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CREATURES OF THE DEEP SEA

The frontispiece shows the following deep-sea creatures: above, an angler fish (family Ceratioidae), seen from in front; below it, the "soft-rayed" fish *Malacosteus indicus* pursuing a prawn (genus *Nematocarcinus*); below on the left, sea lilies of the genus *Metacrinus*, and on the right a squid (*Enoploteuthis leptura*) and the rat tail *Macrurus globiceps*. All are dwellers in the South Atlantic at a depth of about 2500 metres, near the floor of the ocean.

Nearly natural size.

KLAUS GÜNTHER · KURT DECKERT

Creatures of the Deep Sea

TRANSLATED BY E. W. DICKES

GEORGE ALLEN & UNWIN LTD
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CHAPTER I

MAN AND THE DEEP SEA

. . . καὶ κνώδαλ᾽ ἐν βένθεσσι πορφυρέας ἁλός.
. . . and monsters deep down in the dark sea.
Alcman (*c.* 650 B.C.)

Research in the third dimension – Daedalus and Icarus – Alexander the Great as explorer of the deep sea – Dr Beebe and his diving sphere – The sense of a new dimension – The creative urge in science – Man's sense of living

Since early times the European especially has been drawn to the investigation of the natural phenomena in his environment. This thirst for knowledge has become one of the chief characteristics of the Western mind, which, with the aid of empirical science, has changed the face of the earth. And just as the West owes in other fields its formative influences, at work right down to our own day, to the Greeks, it owes to them also the beginnings of the line of thought of empirical science.

And in this field we may attribute the realization, and we might also say the investigation, of the third dimension to Greek influence: it dates from the myth of Daedalus and Icarus, who were said to have made themselves wings and flew up into the sky, and a story of Alexander the Great, who marched through almost the whole of the then known world: according to a later myth he was the first man to descend into the depths of the ocean.

Man has always lived on land, and has therefore been limited to the two-dimensional surface of the earth; in early times he extended his range of movement to include the surface of the water, but he still aspired to move up and down in space—up into the air and down into the depths of the ocean—achievements which almost down to our own day were confined to myth and dream, and at last, quite recently, to countless technical projects. The history of the ultimate conquest of the air does not concern us here; that conquest has developed, before the eyes of those still living, from its primitive beginnings to almost inconceivable perfection. Man's penetration, however, into the depths of the ocean is still in its first stages. In 1934 an American scientist, Dr William Beebe, descended several times, in a steel sphere fitted with quartz windows and a searchlight, to depths of 1500 to 3000 feet below the surface of the sea; and in 1953 Commander Heriot and Lieutenant Willm of the French Navy succeeded in descending to 4000 metres below the surface of the sea (about 13,000 feet) at Dakar.

But the actual feeling of being able to extend the human range of movement into the depths of the ocean has not been created so much by these diving enterprises, important though their results were, as by the diving and under-water research begun nearly twenty years ago by the Viennese Herr Hass and his collaborators, who have penetrated below the surface with no more than a small apparatus that enabled them to breathe under the water and with artificial fins, attached to their feet, to swim with. They cannot, of course, descend by these means into the actual depths of the ocean, though they have been able to explore 150 feet down, a greater depth than can be reached by divers without equipment; but the simple fact of being able to swim or drift in all directions—up and down, forward and backward and sideways—with unimpeded movement through the space accessible to them, photographing and filming, enabled them to convey for the first time, with almost uncanny intensity, the sense of a hitherto unknown and otherwise unrealizable dimension. Such an extension, however, of the human sense of life is one of the most sublime and pregnant inspirations to pure scientific research.

No doubt much that seems in itself worth knowing in pure science is also of immediate practical utility, or—as not infrequently happens in the history of science—subsequently finds opportunities of practical application. But scientific research has never measured the value of its work simply by its practical outcome, and it will never be able to do so without debilitating the creative urge which is its most vital characteristic. Science is not working "for its own sake" even where it does not place in the forefront the question of the practical utility of its achievements: it is guided by the central and vital impulse to heighten the human sense of life: it works for clarification, deepening, and systematization.

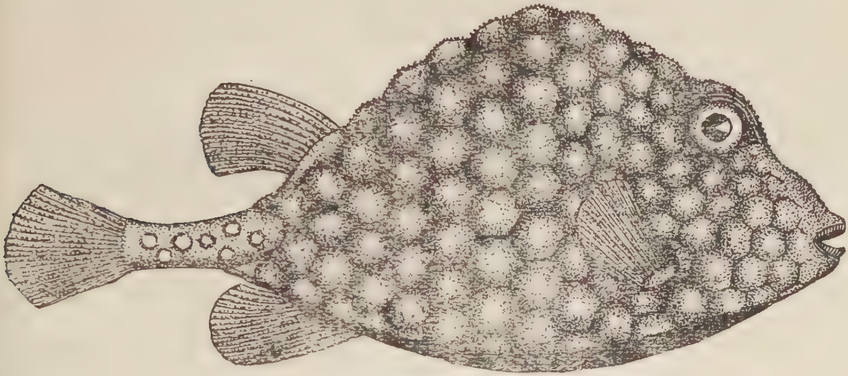


FIG. 1.—A trunkfish (*Ostracion triqueter*). Western oceans. Two-thirds natural size.

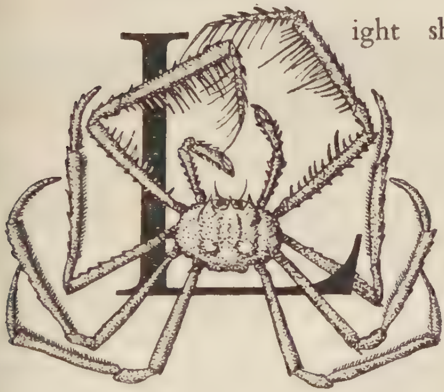
This very fact makes it intelligible that the unknown regions of the earth belong to the earliest and most fascinating objectives of the human urge to research. Among the oldest initiatives, especially of the maritime peoples, is the exploration of unknown lands, such as those which appeared as blank spaces on the map until our own century. Again and again these regions were the subject of disinterested exploration; and much the same blank spaces in the unknown but possibly knowable world have at all times been the summits on land and the depths of the ocean. Man's imagination and his discomfort in face of the unknown populated those depths with weird menacing monsters, and investigation into them might not only enrich his picture of the world but also, and above all, enlarge and clarify and heighten his sense of the life around him and his consciousness of his human destiny and purpose.

For no other reason did Alexander the Great, in the myth already mentioned, descend into the depths of the ocean. And if today we can form a unified picture out of our still imperfect knowledge of the deep sea and its denizens, just as life itself fills the gloomiest abysses of the ocean almost everywhere, in spite of scarcity of light and food, with living creatures, and in those regions has developed a particularly strange and remarkable fauna, we too are filled with a purifying sense of order and clarity and spaciousness when surveying this new-found cosmos. And from the very knowledge of the life in the deep sea we shall be filled with admiration of the way the conformity of all forms of life with universal laws is to be found here in vast, simple, ubiquitous interrelationships, revealing and making intelligible to us a world of living creatures of widely diversified forms, whose wild and exciting picture at first seems to us almost disturbingly strange and incomprehensible.

CHAPTER II

POVERTY AND SAMENESS OF THE DEEP SEA

Poor light and no light – Food scarcity and cold – Plant "autotrophy" – Light and its importance for the existence of living beings – The mystery of the water – The ecological uniformity of the deep sea biotope – Stillness and movement in the deep water



Light shortage or even, at considerable depths, total absence of light; food scarcity, and cold, are the universal conditions of existence for the fauna of the deep sea. The living space of the deep sea—the "biotope" of its fauna, as scientists call the habitat of particular animals or of whole communities of living beings ("biocoenoses"), including plants—is characterized uniformly throughout the world by those features. In its enormous extent it vastly exceeds the widest biotopes on land.

Light, when it impinges on the water, is broken up; some of it is reflected. The component rays of the spectrum penetrate the water in varying degrees according to their wave-length, the red rays, those with the longest waves, being absorbed first and the violet rays penetrating farthest into the depth of the water. Dr William Beebe, who in his steel sphere dived 400, 700, and even 900 metres below the surface, has given an exact description of the way the spectrum of sunlight is rapidly narrowed below the surface of the water. In the clear water of the ocean off Bermuda, where he made his dives, the red rays became invisible to the human eye at a depth of about 50 metres; the yellow disappeared a little below

100 metres. At 200 metres below the surface there was no more than a pale twilight; below that he could see only a steadily deepening blue, until at 600 metres (2000 feet) down the last trace of daylight vanished.

Naturally the depth to which the light can penetrate below the surface of the sea depends largely on the clearness of the water, on the amount of floating matter in it. At a depth of 1000 metres, and in the specially clear Mediterranean even at 1500 metres (but not at 1700 metres), sensitive plates still register traces of light after a sufficiently long exposure. Thus, some of the effects of light may extend to greater depths than might be suggested by the limits of human vision, but it may be inferred from the behaviour of animals and plants that their sensitiveness to light is much the same as that of the human eye.

The extinction of light at relatively small depths is, however, of the utmost importance in its effect on the presence of living organisms in the deep sea—for plants must have light, and all animal life depends on the presence of plants: animals must have plant food, either directly or indirectly—as eaters of plants or as beasts of prey living on eaters of plants. No animal can feed on inorganic matter, on matter belonging to lifeless nature. Only plants can do so; they draw carbon from salts which they extract through their roots from the soil or the water, and especially from the carbon dioxide (carbonic acid) in the air that is dissolved in the water. With this they build their organism: they are "autotrophic". The absorption of carbon, one of the main components of their structure, is possible, however, for plants only through the agency of light. This faculty of plants results from a complicated chemical process which has only been explained to some extent in recent years; the process is one of the most important known factors of life on this earth. Thus without light there is no plant growth, and, indeed, there are virtually no plant organisms in the depths of the ocean. We shall see how in spite of this it is possible for animal life to exist there.

Another consequence of the relatively narrow layer of the sea into which the sun's rays can penetrate is the low temperature at great depths. They receive no direct heat from radiation, only a measure of heating from currents, especially vertical ones such as are found in some regions, and from conduction from the upper layers warmed by the sun. But the effect of such sharing of the warmth of the upper layers is relatively small in the depths of the oceans, because warm water is lighter than cold. The fall in temperature in the descent to lower levels is clearly shown by measurements taken in the Atlantic north and south of the equator.

TABLE I

Temperature readings from 0 to 4000 metres below sea level at various points in the Atlantic Ocean

Depth (metres)	Temperature (Centigrade) at –		
	30° N.	Equator	20° S.
0	24·5	26·0	24·0
150	20·5	14·0	18·5
400	16·0	8·0	12·0
1000	8·0	4·0	4·0
4000	2·5	2·0	1·5

The upper layers of the water are strongly influenced, of course, by the average temperature at sea level at the latitudes at which the readings were taken, by the season, and by the predominance of warm or cold currents in the neighbourhood of the readings. But below 2500 to 3000 metres there rules a fairly uniform temperature of + 2·5 to − 1·5° C.

That such low temperatures, even below zero, in the lowest levels of the sea are possible at all is due in part to the saltness of sea-water. We know that fresh water has the mysterious property of attaining its greatest density (and therefore specific gravity) not at or below freezing-point, but at + 4° C.; on further cooling it

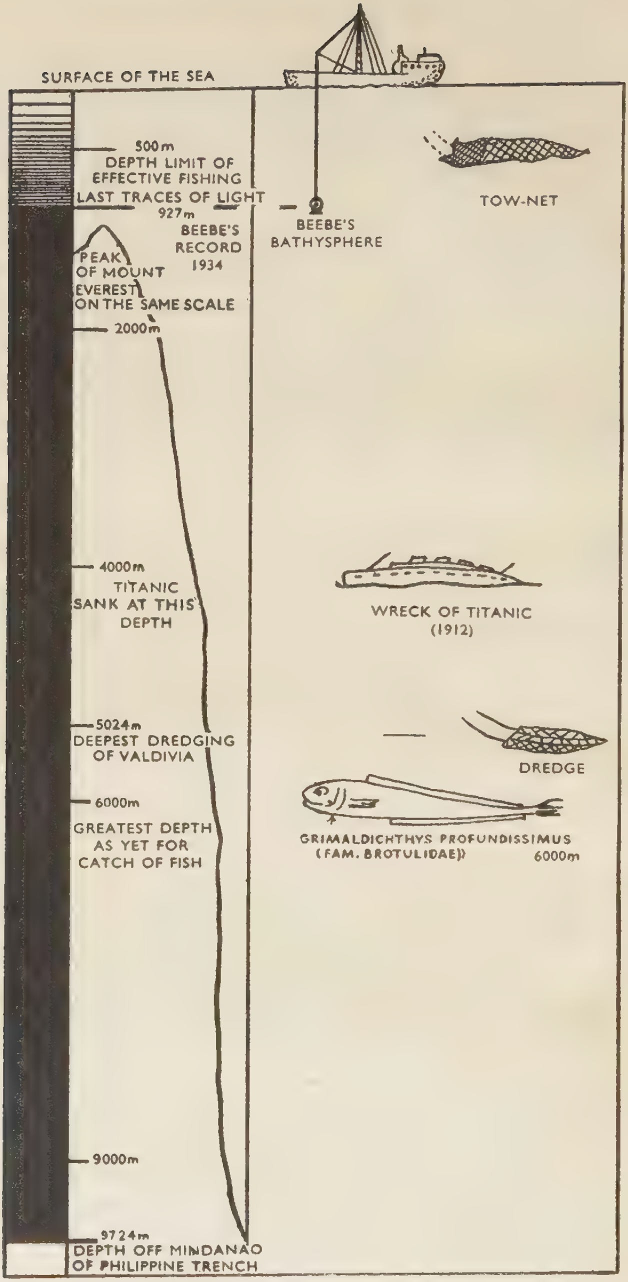

SURFACE OF THE SEA
500m
DEPTH LIMIT OF EFFECTIVE FISHING
LAST TRACES OF LIGHT
927m
BEEBE'S RECORD 1934
BEEBE'S BATHYSPHERE
TOW-NET
PEAK OF MOUNT EVEREST ON THE SAME SCALE
2000m
4000m
TITANIC SANK AT THIS DEPTH
WRECK OF TITANIC (1912)
5024m
DEEPEST DREDGING OF VALDIVIA
DREDGE
6000m
GREATEST DEPTH AS YET FOR CATCH OF FISH
GRIMALDICHTHYS PROFUNDISSIMUS (FAM. BROTULIDAE)) 6000m
9000m
9724m
DEPTH OFF MINDANAO OF PHILIPPINE TRENCH

FIG. 2.—Deep-sea diagram, with data of depth entered to scale.

grows lighter and so rises to the surface. This phenomenon is of the very utmost importance to the biology of fresh water, and, indeed, to the very existence of all life on earth; but it does not apply to water with the salt content of sea-water: this grows heavier as it cools down to its freezing-point, – 1·9° C., so that sea-water continues to increase in density and specific gravity as its temperature falls below + 4° C., and consequently continues to sink to lower levels. Moreover, the enormous pressure in the depths of the ocean brings the freezing-point considerably lower than the sea-level figure here given, – 1·9° C.

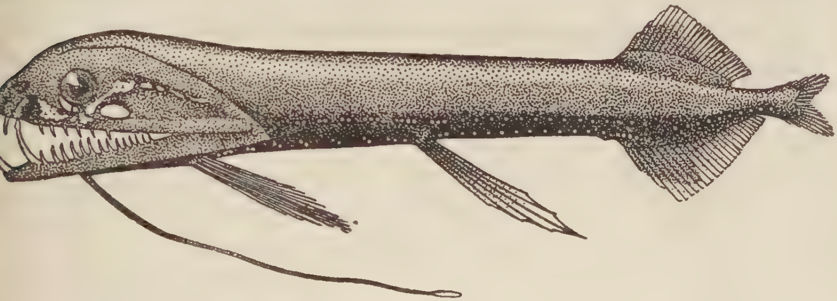


FIG. 3.—The stomiatoid fish *Aristostomias polydactylus*. Caribbean Sea, down to 2000 metres. 1½ times natural size.

The pressure increases by one atmosphere for every ten metres' increase in depth, equivalent to 1033 grammes' weight on the square centimetre or about 15 pounds to the square inch. For this reason the freezing-point of the water in the deepest places in the oceans is considerably lower than the lowest temperature reached there (about – 2·5° C.).

The uniformity of the conditions of existence in the deep sea is produced not only by the relative or absolute darkness and the low temperature, but also by the stillness of the water at great depths. Even the most violent storms and wave movements are almost imperceptible at 60 metres or 200 feet below the surface, and at greater depths the water is virtually motionless. It is clear that animals living in the surface water, which sometimes at all events is in violent motion, and still more those living among th breakers, have very different needs in regard to structural strengt of tissues and skeleton from those of the creatures in the comparatively still water of the deep sea.

But the deep sea is by no means absolutely at rest. Even at th greatest depths there is a certain gentle movement; it consists o slow currents of vast extent, resulting from differences of temperature in the ocean as a whole. Of primary biological importance in this connexion is the gradual sinking of the upper water as it cool toward freezing-point in the neighbourhood of the Poles and it streaming away till it reaches the greatest depths in all latitudes for these movements affect the distribution of foodstuffs, and of th oxygen dissolved in the water, carrying them to the very bottom of the ocean. We shall have more to say about this.

CHAPTER III

A DIVE

Thomas Mann on the deep-sea fauna – The equipment of the deep-sea "bathysphere" – The plankton – The "Portuguese man-o'-war" – The first real deep-sea fishes seen from the bathysphere – Flashes – Habitat of the self-illuminating creatures – Lights, red, green, pale blue – Viper fishes, devilfishes, and angler gnomes of the depths – The fish that is almost all mouth – Three thousand feet down – Six thousand tons pressure on the bathysphere – Insensitiveness of the creatures to the enormous water-pressure – Dr Beebe's record of observations

In his novel *Dr Faustus* Thomas Mann gives expression to the feeling of repulsion which features of the life of the deep-sea creatures must have inspired in him. He makes his hero, Adrian Leverkühn, describe a descent made by him, in a steel sphere, several hundred metres below the surface of the sea. It is evident that the episode is intended as a parallel to the descent into the underworld made by Faust in the old German legend, to which Thomas Mann adheres closely in many features; but, apart from that, he is interested in the details of the dive for their own sake. He fills Leverkühn's report with exciting and impressive descriptions of creatures of "incredible eccentricity, sometimes gruesome, sometimes laughable, created here by Nature and life, forms and physiognomies which retained hardly any resemblance to those of the dry land and seemed to belong to another planet, products of isolation and of habituation to eternal darkness".

Thomas Mann made use, of course, of the account published in 1935 by the American biologist Dr William Beebe of his deep-sea dives (*Half Mile Down*, 1935), heightening the details and anticipating their actual date. But no imaginative treatment could be more interesting and impressive than Dr Beebe's own factual and unadorned account, or, indeed, the unedited record of his telephoned

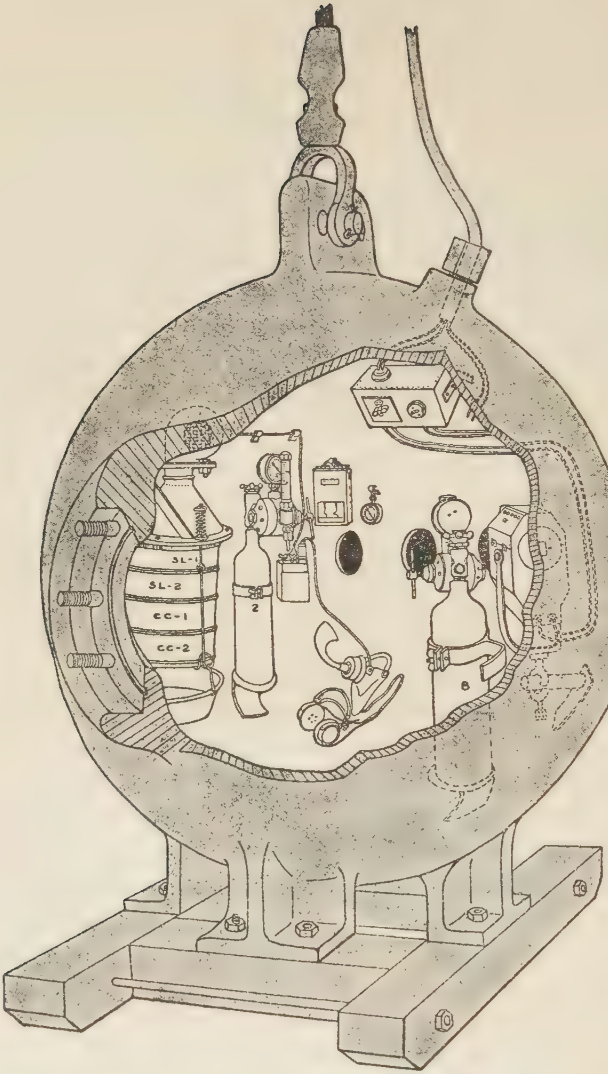


FIG. 4.—Diagram of the deep-sea diving sphere ("bathysphere") used by William Beebe and Otis Barton in 1934. Left to right, chemical apparatus with blower, four trays and a pan (SL soda lime, CC calcium chloride); oxygen tank with valve (2); telephone coil and battery box; automatic temperature and humidity recorder; barometer; switch-box at top of sphere; central observation window directly under switch-box; second oxygen tank with valve (8); searchlight. The telephone cable is shown passing through the stuffing-box into the sphere.

observations and impressions during his dives. These dives took men now living to depths of the ocean never before reached and returned from. They were made possible by the construction of a deep-sea diving sphere by Otis Barton. This was of cast steel, with a shell 1¼ inch thick and an internal diameter of about 4 feet 9 inches; it had three (at first two) circular windows of fused quartz, 3 inches thick and 8 inches in diameter. It was entered through an opening of 14 inches diameter; this was closed by a screwed lid weighing 400 pounds, furnished with special devices for safety. The total weight of the sphere was 5400 pounds, or not much less than 2½ tons. Beebe called it a "bathysphere".

Inside the bathysphere were flasks of oxygen, chemicals to absorb carbon dioxide and moisture, a searchlight, a telephone, and smaller apparatus. The bathysphere was provided with a cable with lighting and telephone circuits, and was let down and hauled up by a steel hawser. Let us picture a descent in such a sphere in the neighbourhood of a tropical coast. We will repeat observations which Dr Beebe reported; but in addition to those we shall hear of many things which the American divers did not see. This will give a first impression of the wealth of living creatures to be found in such a descent, of their strangeness, and of their distribution.

It is most uncomfortable in the confined space within the bathysphere. As it is swung out on a boom from its parent ship and hangs over the water before immersion, the men inside look out through the perfectly clear fused quartz windows. Slowly it is lowered into the water; every moment there is a shorter or longer pause, often only for a few seconds, as ordered by the divers, who telephone the orders and their observations, which are recorded on board.

The water, flooded by the bright sunlight, has a crystalline luminosity, but this continues only a little way down. Here countless swarms of minute organisms become visible, like motes in the sunlight, mostly little crustaceans only a few millimetres long, the "oar-footed" Copepoda (Fig. 5, B, C, D); among them will be some less diminutive "split-footed" Schizopoda, some of them a

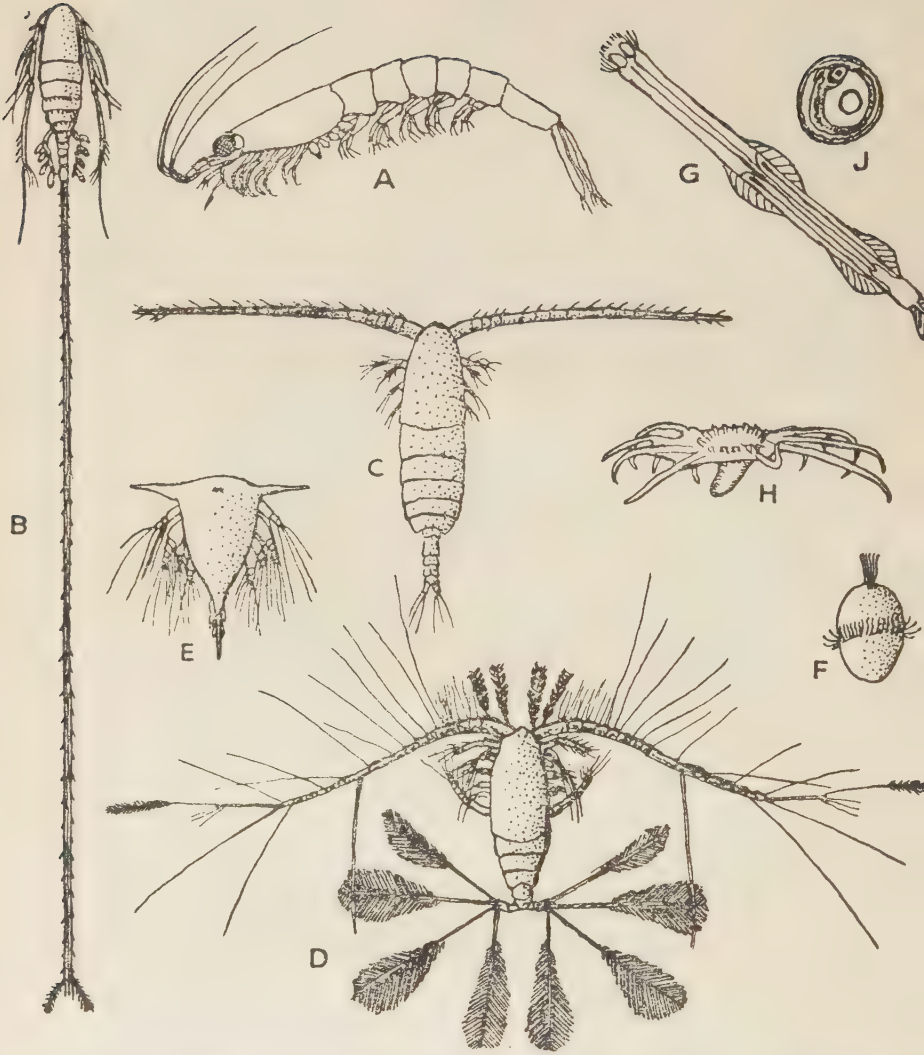


FIG. 5.—Plankton animals of the ocean. A: a schizopod. B: a copepod of the genus *Aegisthus*. C: a copepod of the genus *Calanus*. D: copepod, genus *Calocalanus*. E: "Naupilus", freely moving larva of a barnacle (Cirripede), which in the adult is firmly fixed to a substratum. F: freely swimming "Trochophore", larva of a worm. G: arrow worm (*Chaetognatha*), of the genus *Sagitta*. H: sea cucumber (*Pelagothuria*). J: a drifting fish-egg, with embryo and oil globule.

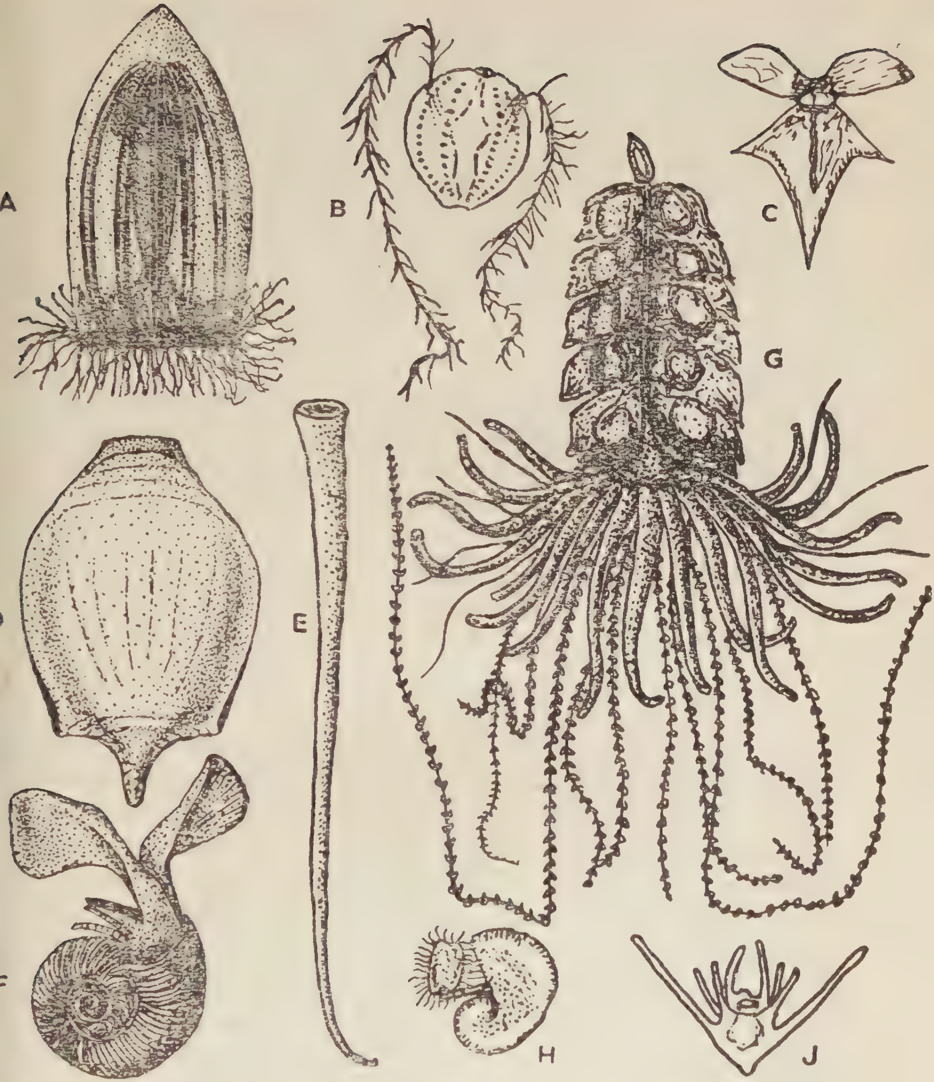


FIG. 6.—Plankton animals of the oceans. A: Deep-sea medusa (*Aglantha digitalis*). B: Comb Jellyfish (Ctenophora) of the genus *Pleurobrachia*. C: sea snail *Clio pyramidata*. D: Shell of the sea snail *Cavolinia gibbosa*. E: Shell of sea snail of the genus *Creseis*. F: Sea snail *Limacina retroversa*. G: a siphonophore, *Physalia hydrostatica*. H: ciliated larva of a snail. J: Pluteus larva of an echinoderm.

few centimetres long (Fig. 5, A), and prawns. These swarms remain equally dense down to a depth of 50 metres; after that they become less multitudinous, and often consist of other species inhabiting the more and more lightless depths; these are found, though only in small numbers, down to the bottom.

It is true that these small creatures are capable of independent movement, the Copepods by means of oar-like strokes of the elongated feelers on their heads, the Schizopods by means of rapid movements of the many little legs on their hind-quarters; but their swimming movements are too feeble and their bodies too small for them to be able to resist any current in the water. They float and drift in the water, so that they are given the scientific name of *plankton*, meaning "that which drifts".

To the plankton belong also the countless masses of the minute unicellular fauna and flora, invisible to the naked eye, with which we shall deal later; and also larger creatures such as jellyfish (Fig. 6, A; 60), salps, pteropods (Fig. 6, F), various worms, etc.

Just at this point a large number of jellyfish swim past the windows of our bathysphere, with rhythmical beats up and down of their "umbrellas"; they are small, scarcely larger than a penny in cross-section, while the largest species related to them may be bigger than the lid of a cask. The jellyfish are among the lowest-organized creatures, and are included with all their very multiform allied species among the "sea-nettles", because the many filaments with which they seize their prey give a nettle-like sting when touched. The body of the jellyfish, the "umbrella", is dome-shaped; this facilitates floating in the water. These fishes swim by raising and lowering the edges of the umbrella. From the edges and the middle of the umbrella hang prehensile filaments. The rest of the body is 98 per cent water, so that when the jellyfish is lifted into the air it drains away almost at once, leaving only a trace of gelatine-like material.

Many species of jellyfish develop in a remarkable way. In their early life they form a colony of individuals firmly rooted to the soil—as other stinging animals do throughout their lives. Later the colony separates into a number of discs on top of each other, like a pile of plates; soon these break away one after another to begin independent life as little jellyfishes.

After that our attention is caught mainly by surface fishes of the tropical sea, many of them richly coloured, others blue or with a bluish shimmer. A few flying fishes rush past, fleeing from pursuit or racing out of the water in simple *joie de vivre*, gliding dozens of yards with the aid of their great breast-fins and then dropping back into the water. Suddenly our bathysphere is surrounded by countless parrot-fishes 18 inches long, ranging in colour from bluish to purple. They owe their name to the horny jaws with which they pluck the little polyps from the coral reefs. Among them butterfly-fishes and drifting mackerel, garfishes and perches, come into sight as our bathysphere drops farther down; a fairly big shark rushes past, quite close to our window, so that we see only a shadow; and unforgettable is the sight, not often secured, of a small trunk fish (Fig. 1) slowly sinking in the sea. The rough leathery skin of these fishes is so thick that they are almost immobilized by it, as if it were armour plate; they can only move their fins. They remain in the still water close to the coral reefs.

Now we drop down more quickly; at 10 metres down the light has already changed in colour, as the red rays of the spectrum have largely been absorbed by the water. Down to rather more than 30 metres our bathysphere can still be seen plainly from on board the ship, as we are told through the telephone. Between 45 and 90 metres down the orange and yellow rays disappear; we are surrounded by a velvety blue-black, quite unearthly, at first luminous and then darker and darker, down to some 300 metres. But we make a halt a little below 100 metres and observe some good-sized squids, slender creatures related to the cuttle fishes, chasing their prey with elegant movements, busily working the fins at the sides of the rear end of their bodies, and their prehensile arms, which play in all directions. The squid, like its close allies the octopods, is distinguished by the possession of muscular prehensile arms on its head, furnished with suckers; its many species form the class of

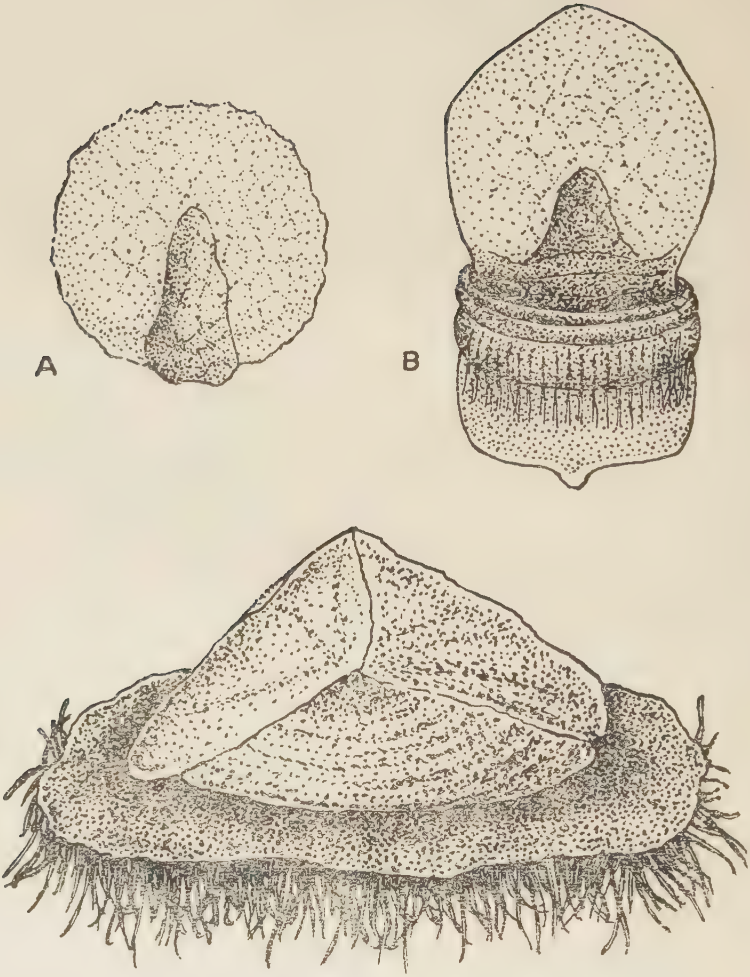


Fig. 7.—Development of the "By-the-wind-sailer", the siphonophore *Velella.* A: Balloon-shaped larva. B: Larva, more advanced stage, with the stem-form of the final animal colony sprouting beneath it. C: Full-grown *Vellella* on the surface of the ocean. A and B greatly enlarged, C slightly.

Cephalopoda ("head-feet"); they belong with whelks and mussels to the phylum of Mollusca ("soft" animals). In intelligence and in the structure of the eyes the Cephalopoda are the most highly developed of the invertebrates; and as we observe them from our bathysphere we cannot but be struck by the size and the expressiveness of their eyes. They all belong to the fauna of the upper levels of the sea, from which other typical representatives, such as the beautiful dolphin-fishes, or the brightly coloured pilot-fishes, are occasionally to be seen, to our surprise, as far as our present depth and even lower.

Now a colony of siphonophores sweeps past our window, a complicated pile of animals, delicate as glass, belonging to the class of the sea-nettles, already mentioned. It is made up of many individuals and yet presents a unified whole. All the members of this unique animal-State take part in the maintenance of the whole State, which assigns particular duties to each of the various groups of individuals belonging to it, the different groups being of different physical constitution according to their particular duty. Some are long filaments with stinging and prehensile capsules; these are the hunters, seizing their prey; others digest it, others serve as organs of touch, and yet others serve simply as swimming bells for transference; these

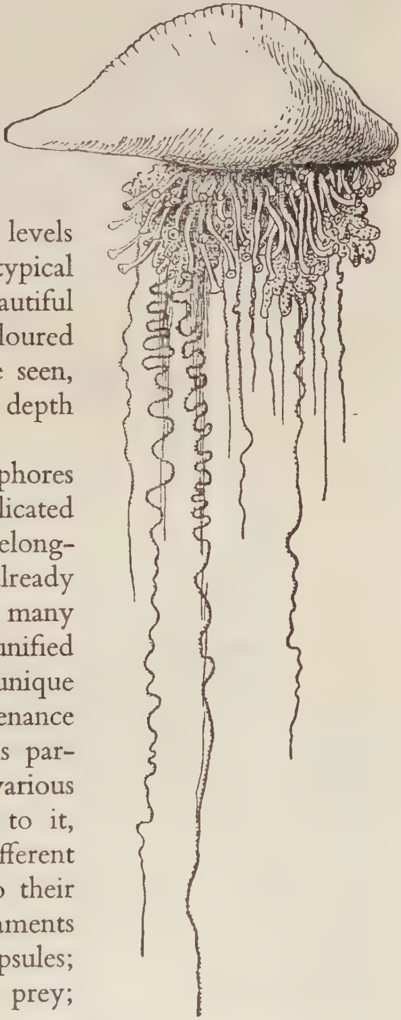


FIG. 8.—The Portuguese man-o'-war or "Before-the-wind-sailer" (*Physalia arethusa*), one-fifth natural size.

last, often of varied delicate hues, hold the whole pile of animals afloat and upright. In many species the top member is filled with gas. By changing the pressure and quantity of gas in these containers the jellyfish State is able to rise or drop down without actual physical effort.

Many species of these jellyfishes appear in all the oceans, and they are met with at very considerable depths; the most famous of them are the "Portuguese man-o'-war" or "Before-the-wind-sailer" and the Velella or "By-the-wind-sailer", as they are called by seafaring men: they live as fully developed stems of animals permanently on the surface of the water, above which their great "gasometers" rise into the air. They are furnished with high-flying crests or combs by means of which they sail over the high seas, often in great shoals.

We drop down into the increasingly night-like blue, and now we begin to use our searchlight, at first only for 20 or 30 seconds, or at most 50, so as not to dazzle ourselves too much, and also because in the close confinement of our bathysphere the searchlight gives out fearful heat. In the path of its beam there appear again and again dense clouds of small plankton animals, principally the little copepods or oar-footed crustaceans already mentioned. And now comes an exciting incident: a shoal of silvery fishes race past us, ravaging, with their mouths gaping horribly, among these swarms of little crustaceans. Quickly the pursuers pass out of our field of vision; undisturbed by what is going on, some delicately beautiful pteropods, species of the genus *Clio*, with translucent fluted shells, have been passing at the same time on their leisurely course, while for a moment a big-eyed deep-sea lantern fish plays round our window (Fig. 11).

We switch off our searchlight, and realize as we begin to breathe that we have seen the first true deep-sea fishes in our dive. Those little silvery fishes (*Cyclothone signata*), only a couple of inches long, are perhaps the commonest of all deep-sea fishes in the tropical Atlantic; they live at a depth of 130 to 500 metres below the surface, and their place is taken farther down by other species of the same

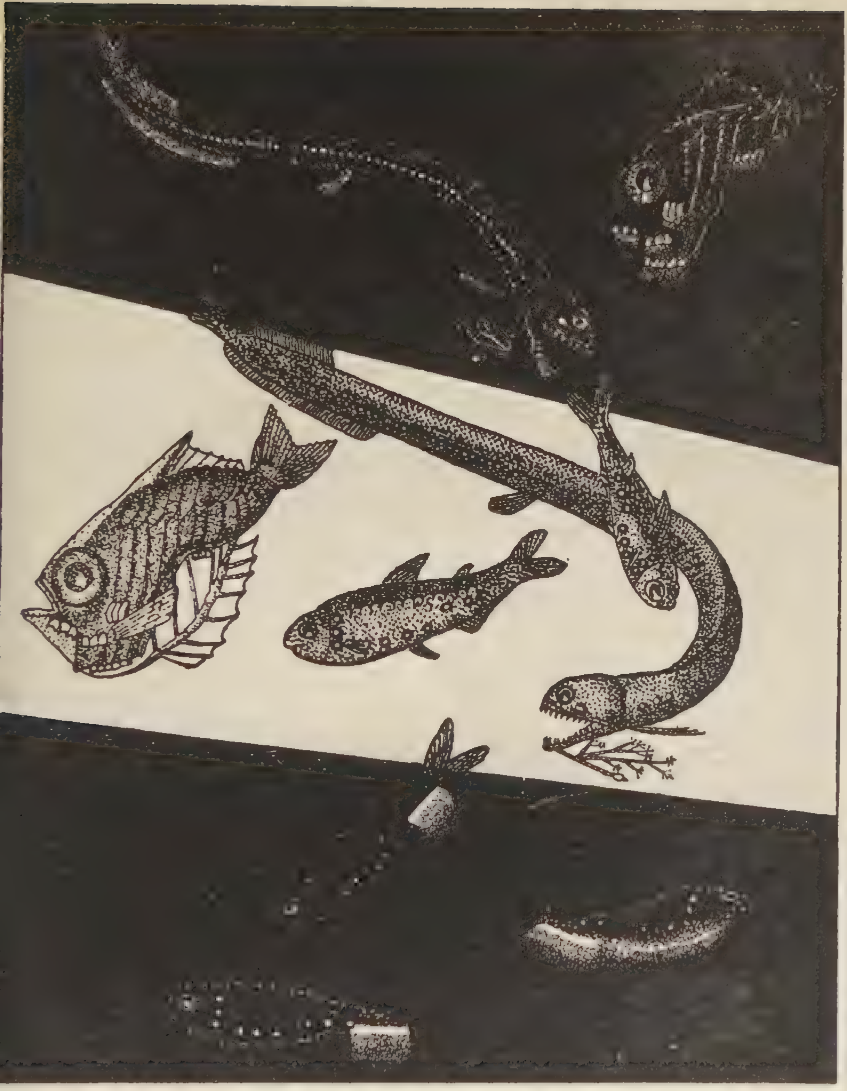


FIG. 9.—The deep-sea stomiatoid fish *Eustomias satterleei* hunting lantern-fishes (genus *Myctophum*). Next to it is the hatchet fish *Sternoptyx diaphana*, a transparent fish with folded breast. Off Bermuda, 2000 metres down. The middle section is lit by the bathysphere searchlight. Natural size. (See page 41).

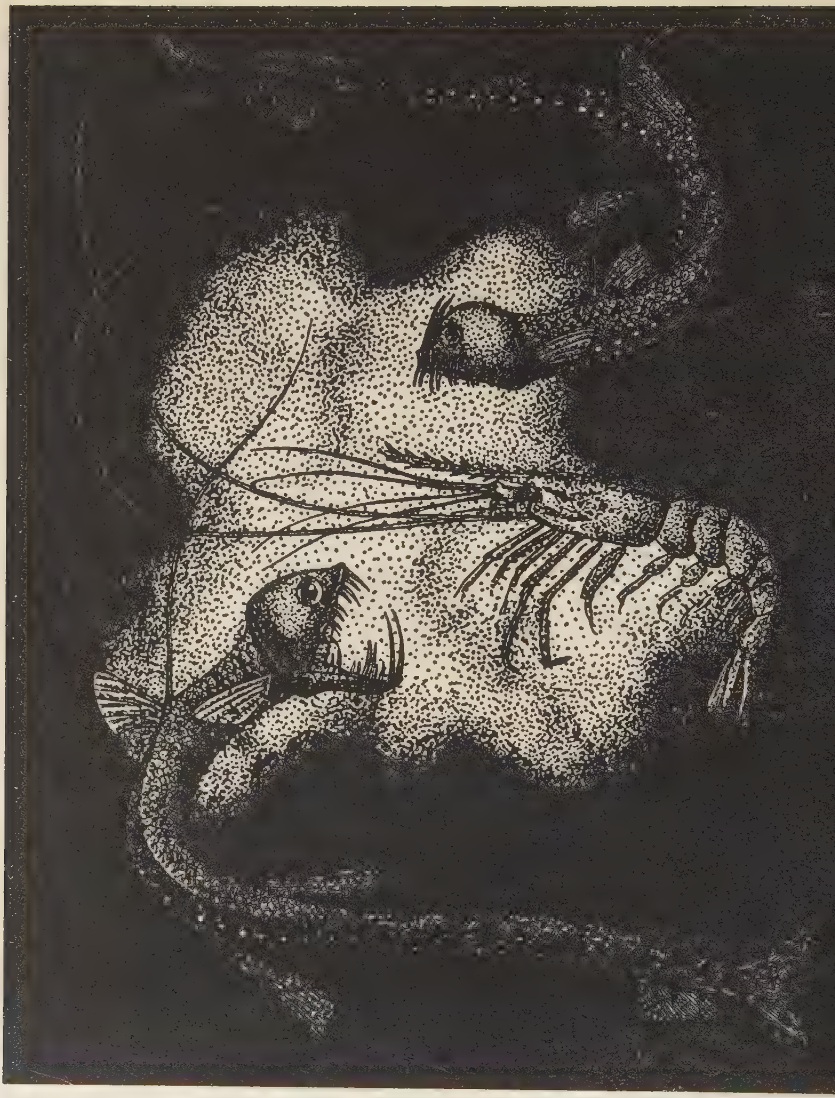


FIG. 10.—The viper fish (*Chauliodus sloanei*) seizing a red prawn of the genus *Nematocarcinus* which has tried to protect itself by ejecting a luminous substance. All oceans, 1000 metres. 1½ times natural size. (Page 38.)

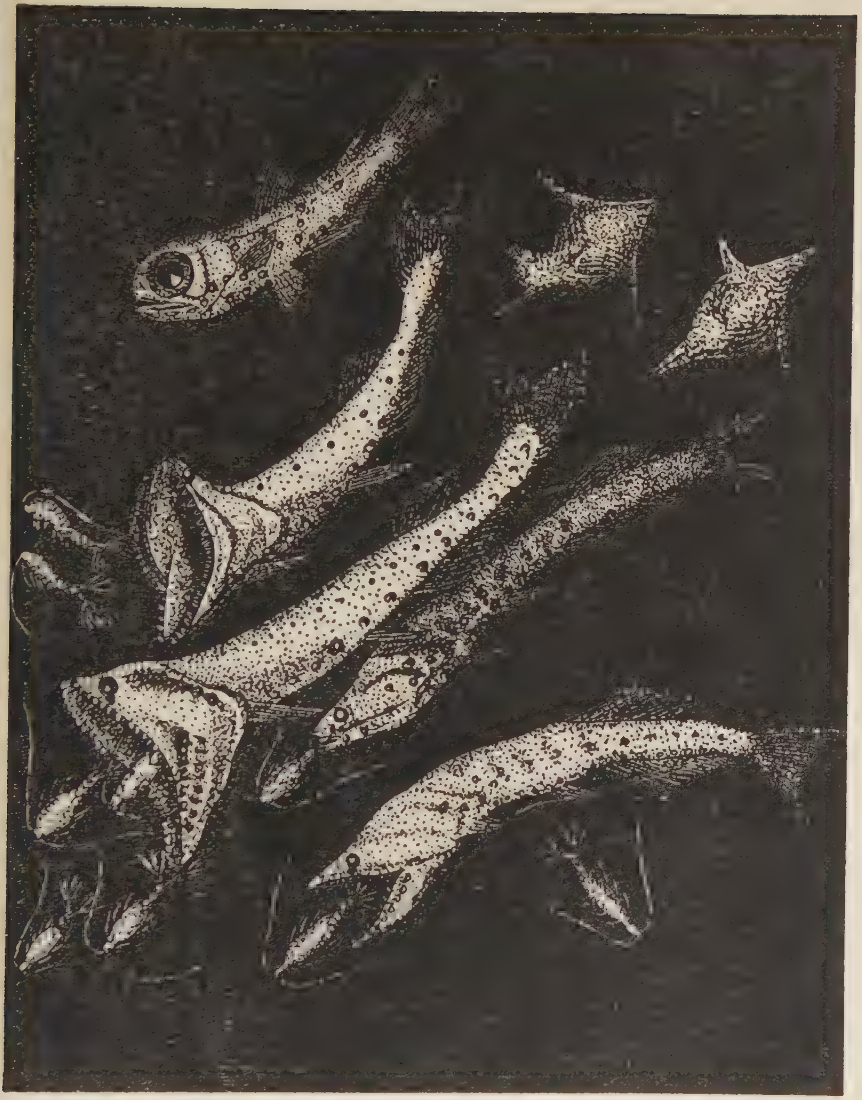


Fig. 11.—The deep-sea fish *Cyclothone signata* hunting copepods; above it a lantern-fish (genus *Myctophum*) and sea snails (Pterodpoa) of the genus *Cavolinia*. 1½ times natural size.

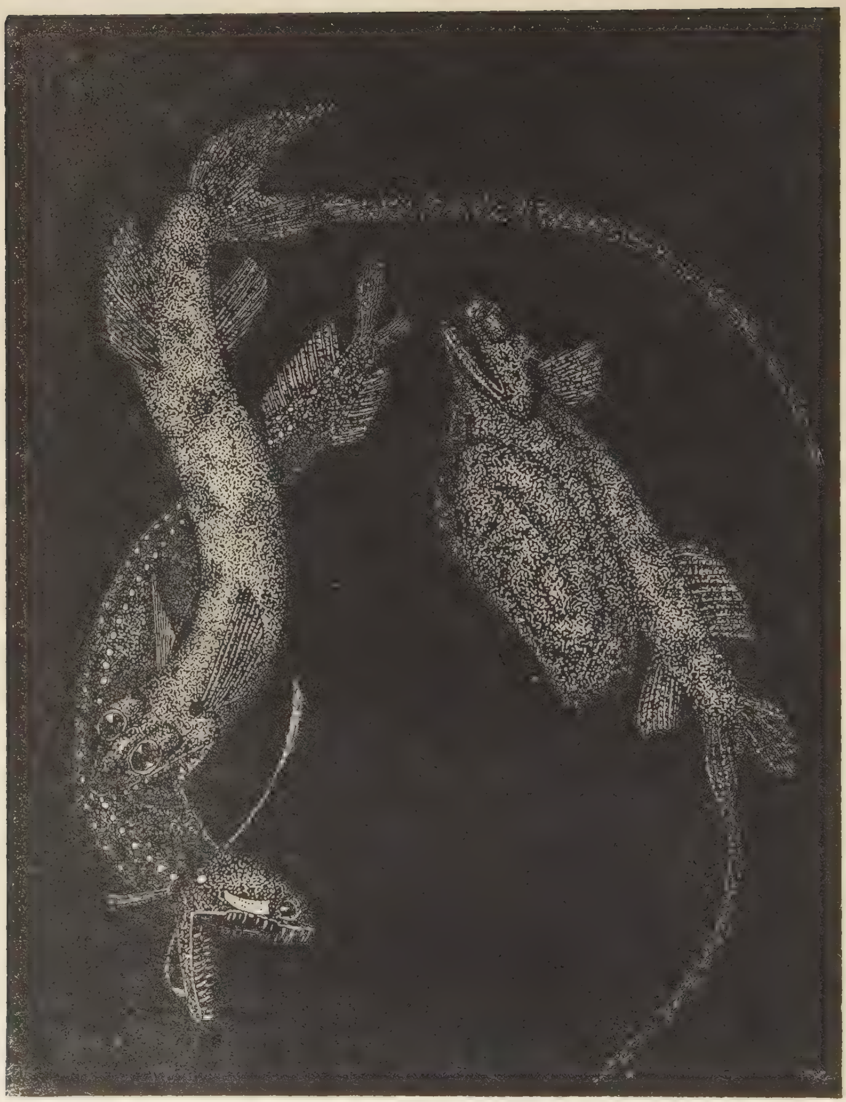


FIG 12.—Giant-tailed fishes (genus *Giganturus*, Eastern Atlantic, 1500 metres down), feeding and after feeding. Natural size.

genus. We were able to see quite clearly their sharp little teeth, crowded round their wide-open mouths. The Cyclothones belong to the great family group of the Stomiatoidea, with which we shall have much to do, as it consists almost entirely of denizens of the deep sea, most of them of strange and fearful appearance (Figs. 10, 11, 12). The lantern fish belongs to the order of the Iniomi (which is also made up largely of deep-sea dwellers), and to the genus *Myctophum*, many species of which are known in all the oceans. The species we saw has striking characteristics, common to many deep-sea fishes: they have great eyes, which facilitate seeing in the regions of dusk in which they live. The various species of *Myctophum* are caught in nets, usually at much greater depths than the 170 metres or so at which we found them. The body of the *Myctophum* is furnished with numerous light organs, variously arranged from species to species and even between the sexes, but we were quite unable to detect these organs in the strong beam from our searchlight, and equally unable to detect the still more numerous minute light organs of the silvery Cyclothones.

The next time we prepare to switch on our searchlight we look out into complete darkness, with nothing visible but a small sea gooseberry, about the size of a nut, of wonderfully delicate form, and luminous, with two long tentacles playing in the water. It passes close in front of our window, apparently moving up, as we are quickly dropping lower. It moves gracefully and steadily, through the beating of countless small plates arranged like ribs—hence the German name, meaning "ribbed jellyfish"—across the body (Fig. 6, B).

And then, at a little more than 200 metres down, there come some very bright flashes, like lightning, evidently produced by animals that can turn their light organs on and off at will. But before we can distinguish anything; light, colour, and the forms lit up are but a faint memory. We feel ourselves to be in a world with no resemblance to the world we know, with forms that "seem to belong to another planet", as Adrian Leverkühn says in Thomas Mann's *Dr Faustus*. Soon the perplexing lights multiply; fishes with long rows of lights, like a ship's but of every imaginable colour, move past us, themselves indistinguishable, while others are visible through a weak phosphorescence that reveals their whole form, or at least their head and enormous teeth; they pass spectrally, as if dipped in an illuminant, through the inconceivable blackness of their environment.

These are revelations such as were never before possible or thinkable. More impressively than any examination of creatures brought up from the depths in a net could lead us to expect, we see with our own eyes that the dark depths of the ocean have become the dwelling-place of self-lighting creatures. The lights in front of us are as multitudinous as those of the starlit night sky, though very different, as here in the deep sea they move, shoot to and fro, blaze up and go out, and send out rays of all colours. And never has a trawl net conveyed the picture of such a wealth of living beings in the deep ocean as we now have before our astonished eyes! This gift of self-illumination, displayed in so many different ways, is not confined to fishes: it is possessed also by jellyfishes, prawns, squids, and other animals. But not all of them have special light organs, or have them permanently. Prawns secrete a luminous mucus, to frighten away their enemies; squids employ another such device. Instead of the dark contents of their ink-sac, with which species living in the surface water surround themselves for concealment, the deep-sea squids eject a luminous fluid in order to evade pursuit: to spread a dark fluid in the depths would not help them. Even the fishes with light organs are often able to light up whole sections of the surface of their body, their fins, and especially the head and teeth, with a faint phosphorescence; probably a luminous slime is passed over the areas affected.

And in what bizarre, and indeed unimaginably grotesque forms do the beings of this spectral and exciting world reveal themselves to us as we sink lower and lower! Often our impressions crowd one another out, as we have not eyes enough to take in all the strange sights at our window. Now there passes a little way from the window a fish with faint illumination of its head and back and its long and formidable teeth (Fig. 3). It wriggles its slender outstretched body, which has a row of pale blue lights along its whole length, like the lights from the scuttles of an ocean liner, and a red and a green light, both larger than the others, at the sides of its head, shining straight into its own eyes. A long thread, at least partly lit up, hangs from its chin and plays in the water beneath it. Suddenly a quantity of spots, no bigger than pinheads, glow brightly all over its body and then go out. At the same time there come past a whole shoal of wonderfully delicate and beautiful little "Zeppelin snails", in their very thin, transparent cylindrical shells; among them is a big jellyfish with a confusion of thick prehensile filaments, slowly working its way up by means of powerful beats of its phosphorescent umbrella. Meanwhile there is a sudden increase in the remarkable blaze that has been coming again and again from all sides some way off—a perplexing phenomenon of which we now see the explanation: shoals of luminous deep-sea lantern fishes are racing towards us; the outlines of the little fishes are faintly visible through the light organs distributed all over their body, and they repeatedly send out from below, just in front of their tail, a sudden blaze so bright as almost to dazzle us. We see at once why they are in such a hurry: they are fleeing from some beasts of prey three or four times their size, which are pursuing them with their jaws wide apart and great teeth inside them (Fig. 9). With their row of side lights and with the coloured searchlights on their head shining straight into their eyes, they resemble the fishes described above, but their fins are also faintly lit and the short, much-branched chin-barbels gleam like the tinsel on a Christmas tree. Dr Beebe had caught some of these fishes in a net, and named them "Satterlee's stomiatoids" (*Eustomias satterleei*), after a patron of the New York Zoological Society, as they had been unknown to science till then.

All that, however, belongs to the past, like this wild chase, but we continue to look through the window as if under a spell, until we start back: quite close to us some dark, unseen animal must have exploded into a veritable cloud of fiery particles, which float in the water for a short time before they fade away. We turn on the searchlight, but there is nothing to be seen, and we are baffled by the uncanny incident. But as we are about to switch off the searchlight we stop, speechless: for there now appear in its bright beam three big fishes, a yard long, such as no man has seen before. They have little eyes, thread-like pectoral fins, and sail-like, triangular dorsal and anal fins far back on their body, but only a tiny tail-fin. Their mouths seem almost toothless, and they are an ugly sallow colour, like waterlogged or putrid flesh. In our excitement we forget to telephone our observations, so that those on board become disturbed and ask whether anything has gone wrong; and before we can fix all the details in our memory the fishes disappear. They have never been seen since, still less caught: we surmise that they may live at much greater depths than we can reach.

We are now 650 metres down, and have not a minute to spare for thinking about the fantastic situation in which we find ourselves, not much less than half a mile below the surface, lost in the immensity of the ocean, and protected from the enormous water-pressure only by the stoutness of our little steel sphere at the end of its steel hawser. We may shudder for a moment at the thought that our quartz windows may not be proof against the pressure; if the water forced its way in we should be crushed before we drowned. But our flasks are steadily yielding the life-giving oxygen, while the carbon dioxide is no less steadily being absorbed by the calcium chloride in the containers above us. In this respect we have nothing to complain of. But our confined position, with our legs drawn up under us, would be trying indeed if we had a moment to think about it. For in the blackness of the water around us the multitudinous lights have increased rather than not. It would become monotonous if we were to reproduce all our observations. Again and again, too, we remain uncertain what it is exactly that we are looking at. Very frequently we find that it is these fishes with a single or double row of lights along their bodies, the filaments, often luminous, hanging from their chins, the great teeth, and the coloured searchlights glaring into their own eyes; many of these are species of stomiatoids familiar to us from books and from trawling catches. We wonder that these fishes are not blinded by their own lights. And now and then we see lights in the distance, about the size of half-a-crown, which we can only attribute to stomiatoids. But the bearers of such great searchlights must be very big fishes, while we have never actually seen or caught any of greater length than a foot or fifteen inches.

Then, while some luminous fishes a few inches long are rushing past our window, there is a repetition, close in front of us, of the

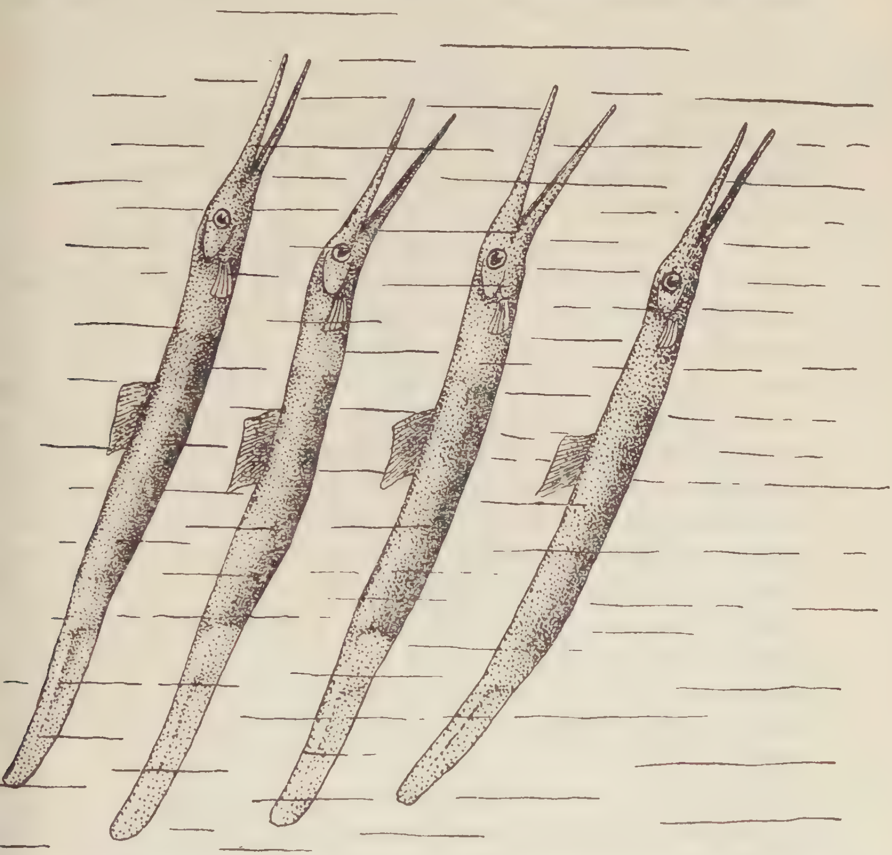


FIG. 13.—Fishes swimming almost straight up, seen by Dr Beebe on one of his dives. They have never been caught. Two-thirds natural size.

extraordinary bursting of some creature into a mass of sparks; but at once we switch on our searchlight, and now we can see what is happening: a fine red prawn, not glowing, has expelled this cloud of luminous matter (Fig. 10), in order to conceal itself from its pursuers. That is the solution of the mystery. But this time the stratagem does not help the prawn; one of its pursuers seizes it. Its captor is one of the really fearsome Viper fishes that pounce on their prey, shake it for a moment, and swallow it. With their incredibly wide-open jaws and throats they are truly appalling, but no less so with the jaws closed, for then the teeth that can find no room inside stand up outside like the tusks of a wild boar. Fortunately these fishes grow no bigger than the one in front of us; they too belong to the class of stomiatoids. They gulp down fishes half their own size. Their stomach can stretch enormously, as if it were of rubber.

At 700 metres (2300 feet) we are approached quite closely by two orange-coloured lights, playing to and fro with curious irregularity. We switch on the searchlight, and see a great red decapod, a ten-armed squid, similar to the cuttlefishes of the surface water, swimming towards us. At the end of each of its two longest arms or tentacles it has two globes sending out the orange lights we saw. It is hunting, and with the suckers on its tentacles it is holding a number of Schizopods, crustaceans about an inch long. This species of squid has never been caught, and so is entirely unknown. We have seen smaller luminous squids of other species from time to time. A little lower down a couple of thin snipe eels wriggle past our window; they are certainly 30 inches long, and have immense eyes and strange upper and lower jaws, thin as needles, bent away from each other above and below, and running together at the inner end (Fig. 82). We have no idea what use they make of them.

Just after this we have a most unexpected encounter: into the bright beam of our searchlight come four slender, long-beaked fishes, swimming quite stiffly almost straight up, and keeping at a fixed distance from each other. They are more richly coloured than

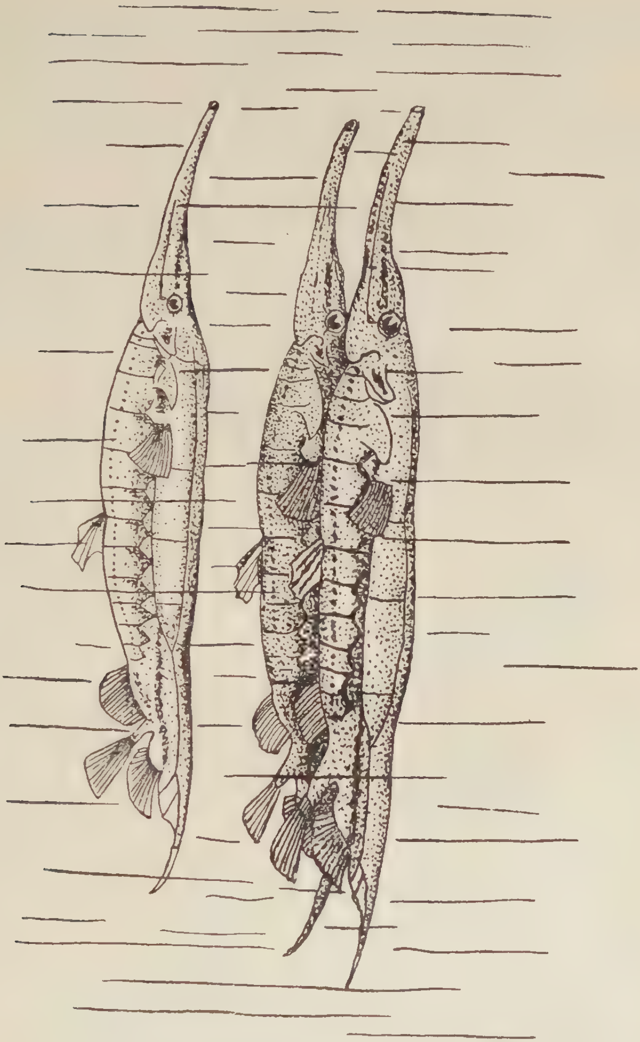


FIG. 14.—A shrimp fish (*Aeoliscus strigatus*), of the upper levels of the Indian Ocean and the Pacific, swimming in a vertical position. Natural size.

any other deep-sea fishes we have seen. Beak, head, and breast are scarlet, belly a luminous blue, and the rest of the slim body pale yellow (Fig. 13). We are captivated by their strangeness and their lovely colouring, but they quickly disappear into the darkness. They are entirely unknown: can they be related to the garfishes? We do not know; we recall a shrimp-fish of similar form in the Indian Ocean, but in the surface water; it swam similarly with the head high. This unusual posture is probably connected with the position of its fins: the back fins are at and even below the end of the body, and the tail fin right under the body before its end (Fig. 14). In that fish, however, the head is not prolonged by a beak but by a tube with a tiny mouth at the end of it. In our deep-sea fish, on the contrary, we think we remember the beak-like prolongation of the jaws, and the back fin halfway along the body. It made use mainly of this fin for propulsion, like the sea-horses, which also swim upright; thus it cannot be related to the shrimp-fishes of Ceylon. We were puzzled in this case, as with almost every denizen

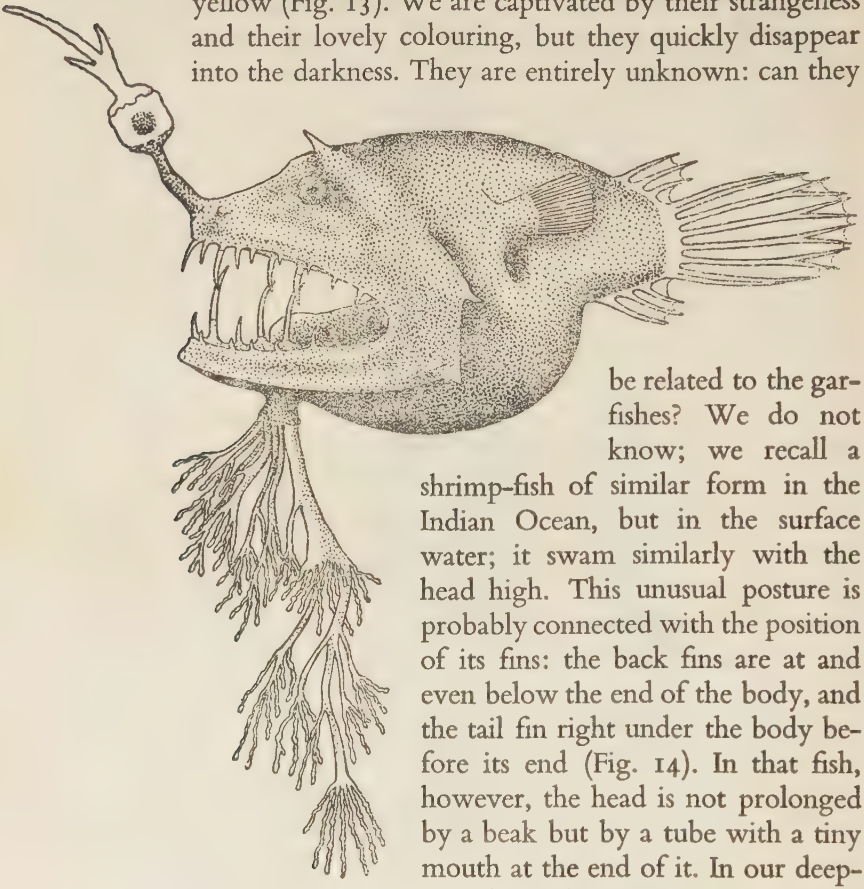


Fig. 15.—The deep-sea devilfish, *Linophryne arborifer*. Atlantic, 400 metres. Natural size.

of the deep sea, by the indifference shown to the beam of our searchlight: the fishes gave no sign of being alarmed or even disturbed by it.

In these depths the animals of the plankton are still frequently to be found. In addition to the copepods, which are often splendidly iridescent in our beam, we see swarms of the rather larger schizopods and especially the pink, translucent arrow worms.

And now one of our greatest hopes for this dive is fulfilled, a meeting with the incredibly absurd devilfishes of the depths (Fig. 15). Out of the darkness comes obliquely towards us a phosphorescent throat armed with enormous teeth, with a little light swinging above it like a lantern. We switch on the searchlight, and, sure enough, there in front of us is a devilfish or angler, going slowly on its way. We are breathless with excitement at seeing one of these grotesque monsters alive. Various species are familiar to us in net hauls and in books. The fish is as broad as it is long, and as tall as it is broad, something of a nightmare vision but for its small scale; it is no bigger than a man's fist. It is a *Linophryne*, and in addition to the lantern on its head it has a big appendage hanging from its chin, crescent-shaped and branched: this does not seem to be luminous. The beast is moving lethargically, and slowly enough for us to have a good look at it. We do not see it eat anything, but it can certainly, with its gigantic jaws, eat fishes bigger than itself, luring them with its lantern and snapping them up. For the lazy thing is obviously no hunter: it must wait for whatever may turn up, tempted by its lantern. We suspect that the branched appendage under its chin contains sensory cells that tell it the size of anything approaching and its line of approach, so that the devilfish may prepare accordingly. The sensory organs may be a very good recorder of the strength and direction of waves set up by the victim as it draws nearer. The devilfish has no sooner dived back into the darkness, of which it must be a highly respected inhabitant, than a shoal of high-backed hatchet fishes, little things three or four inches long, come into view (Fig. 78); their many lights give a metallic gleam to their big scales, as if they were crumpled tinfoil.

They have "telescopic eyes", standing straight up. They are generally found at less than 800 metres, the depth we have now reached.

We hesitate about venturing lower; but we are eager to penetrate farther into the wonders of the deep, and perhaps to see other living creatures which we do not expect to find till we are nearer 1000 metres down. The lights and flashes round us are almost undiminished; only at about 800 metres does the astonishing multiplicity of luminous creatures seem to fall off. But now we meet with a pair of the brightest of them: two "Nose-Lanterns" of the genus *Aethroprora*, about a foot long, come quite close to our window. They are allied to the lantern fishes, with a great light organ, giving a bright yellowish glow, on the front of their head, between the eyes, and many smaller lights along the sides of their body (Fig. 17).

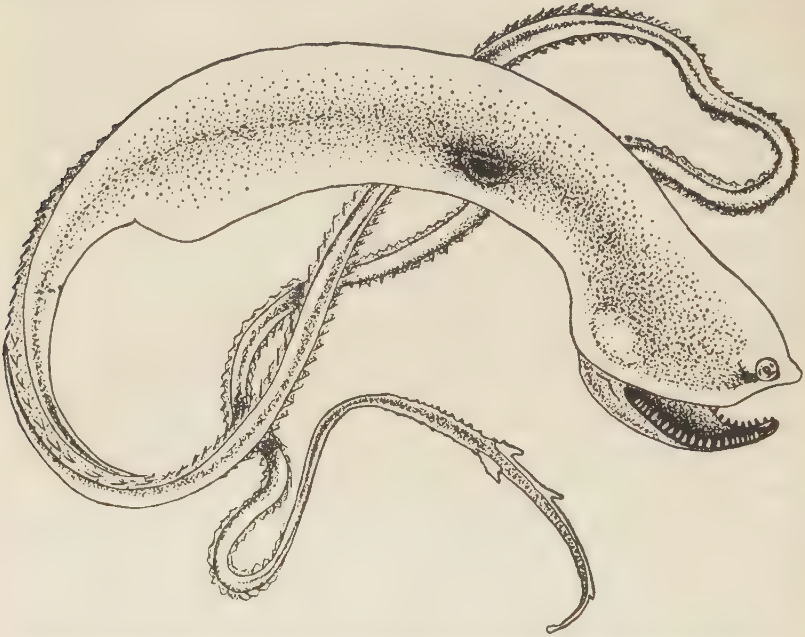


FIG. 16.—The gulper-eel or pelican-eel (*Saccopharynx harrisoni*), off Bermuda, 1600 metres. One-quarter natural size.

Then, a little lower, we find what we had not dared to hope for, one of the uncanniest deep-sea monsters, a Harrison's gulper (genus *Saccopharynx*), almost five feet long, though most of this length is made up by its threadlike tail (Fig. 16). The Germans call it the Pelican eel. It is the red glow of its spiky tail that first attracts our attention. We switch on the searchlight and look with dismay at this black beast, which is moving ponderously towards us. Its belly is swollen out of shape by what is obviously a very big fish it has swallowed, and its sack-like mouth with the little eyes above it is wide open as the eel faces us. We are familiar with allied species from net hauls, and some have still bigger mouths, but it is eerie enough to meet with this great *Saccopharynx* and to look down that insatiable abyss. We watch it for almost a minute, until the glowing tip of its tail disappears in the darkness. It is a spectral denizen of much lower depths than we can reach.

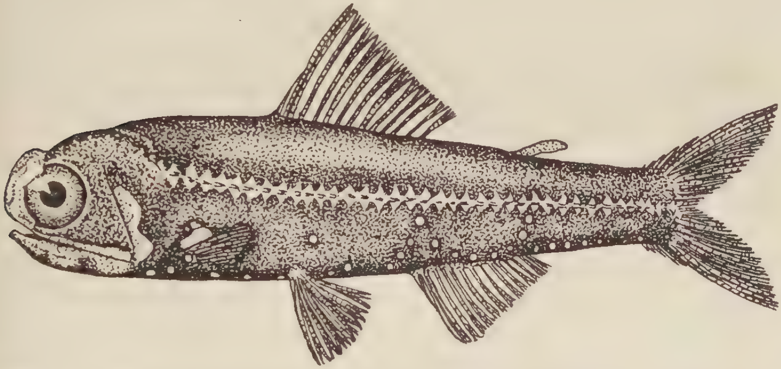


FIG. 17.—The luminous-snouted lantern-fish (*Aethroprora effulgens*). Caribbean Sea, down to 3000 metres. Two-thirds natural size.

We have descended now more than 900 metres—about 3000 feet—and a message from on board our parent ship tells us that it is felt to be inadvisable to unwind our 1000-metre hawser further. So we have reached the lowest point in our dive, but we are still 2500 metres above the bottom of the ocean, which here is 3450 metres deep (over 2 miles). It is uncomfortable to reflect that here, at a depth of some 3000 feet, the pressure on our bathysphere of the vast mass of water above us is over 90 atmospheres, which means a total weight of 6000 tons pressing on the surface of the sphere, whose strength and form are our only protection from being crushed to death. The pressure on each window is 35 tons.

How do the creatures of the depths, many of them delicately built, withstand this enormous water-pressure? They notice it no more than we on land notice the pressure of the atmosphere, which bears on every square inch of the surface of our bodies with a weight of 15 pounds. The explanation of the insensitiveness of the deep-sea animals to the pressure on them is the same as in our own case: internal and external pressures balance. All that is dangerous is the sudden disturbance of the balance. Just as a quick ascent of thousands of feet in an open aeroplane is injurious to health, so the sudden change of pressure when deep-sea fishes are brought up in nets is fatal to them.

And now we move up again, as slowly as we came down, and continue our observations and our telephone messages for recording on board. At 500 metres we notice the first faint glimmer of daylight—not in the water outside but on the lower rim of our windows, as a reflection, since the last weak traces of the daylight are visible only where it falls perpendicularly from above. Our dive has lasted just under three hours from the first dip into the water to the final heaving back on board. Then we are nearly deafened by the noise of the hammering to unscrew our lid. With painfully stiff limbs we worm our way out through the narrow opening into the sunlit air, enthusiastically welcomed by those on board, who have been following the events of our dive with intense concern.

Dives which, unlike that here described, actually took place, were made in 1934 by William Beebe and Otis Barton, and were made again by Barton in 1949. To give an actual sample of Dr Beebe's own impressions, we here reproduce an extract from the record of his telephoned observations, relating to part of the return journey from 2000 to 1600 feet below the surface, in a dive made to a depth of 2530 feet on August 11th, 1934.

UNEDITED TELEPHONE OBSERVATIONS ON DIVE NUMBER THIRTY

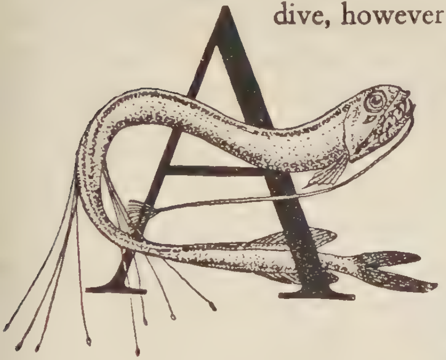
Feet	*Time a.m.*	*Observations by William Beebe*
2000	11.50	Absolute dead black.
1960		6 lights in a row on separate animals close to window.
1930	11.51	Something like a rocket bursting.
1900	11.52	School of luminous fish, not *Sternoptyx*, not *Argyropelecus;* a 5 by 6 inch fish with 4 or 5 lines of lights, yellow, with purple circles, 2 lines very distinctly curved up above middle line and 2 more curved below. More about it when I come up. Remind me. It disappeared by turning head on. New fish! First faint glimmering of sun's light on white quartz window packing.
1800	11.54.10	No lessening in brilliancy of sparks.
1770		School of fish like Myctophids, 3 to 4 inches, they light up as they weave in and out, about 30 in school.
1730		Decided luminosity. Can see a little with eyes.
1700	11.56	Barton can see my face in the dilute daylight; can count fingers against window. More light than on other dives!
1670	11.57	Haven't seen any really blue luminescence before, these are decidedly blue.
1660	11.58	Bright light.
1630	11.59	Light as big as an American penny, this creature with patches on it. Barton saw something explode and break up.
1600	11.59.10	Brilliant animal lights, water colour, a cold colourless light slowly increasing.

The scientific data contributed by these dives to research concerning the fauna of the deep sea consisted mainly in the observation of many of these creatures as living beings, and—in so far as they have any—observation of their light organs, which had never before been possible. (It had only been possible, for instance, to conclude from the dissection of those organs that they produced light.) These dives also established that at least the levels of the ocean which had been passed through are more thickly populated than had been supposed; that many deep-sea creatures frequently rise to higher levels of the water than they had been known to reach, and that in the depths larger animals were to be met with than had been inferred from catches—according to Dr Beebe's observations, creatures between six and twenty feet long. Dr Beebe believed, indeed, that at a depth of some 3000 feet the number of large fishes seemed to increase. In general, his observations showed that it was quite clear that by the methods of capture employed hitherto only the smaller and the lethargic animals could be obtained, the larger and the more active ones escaping.

CHAPTER IV

THE EXTENT OF THE DEEP-SEA REGION AND THE HISTORY OF DEEP-SEA RESEARCH

Two-thirds of the earth's surface – The "abyss" theory – The Sardinia cable – North Africa and the beginnings of deep-sea research – The "Challenger", "Valdivia", and "Siboga" expeditions – Thick quarto volumes – Victor Hensen's count of the plankton – Dredging, trawling, and plankton netting.



A dive, however, such as that described above cannot serve for any close study of the creatures observed: the safety of the diving bathysphere and its resistance to the increasing water-pressure depend on its complete isolation under water from everything outside it. What means, then, exist for the study of the structure and the adaptations of deep-sea animals? And, to begin with, what is the extent of the field of that study, the deep sea itself?

The depths of the oceans were explored in the past by direct sounding, and more recently (since 1920) mainly by means of echo-sounding apparatus, by which directed sound-waves are sent to the bottom of the ocean. The exact speed of transmission of the sound-waves through the water is known; they are thrown back from the floor of the ocean as an echo and received by the sending ship, and the depth at the spot thus sounded is ascertained from the lapse of time between the sending of the (ultra-sonic) sound waves and the arrival of their echo.

Countless soundings have been made in the past, and give us an adequate and sometimes a very detailed profile of the floor of the ocean, with its depressions, its "trenches", and its ridges. The greatest depth sounded, in the so-called Japan Trench and Philippine Trench in the Pacific, amount to some 10,500 metres or 35,000 feet, and it has been calculated that the average depth of the seas throughout the world is about 3800 metres or 12,500 feet. This gives an enormous extent for the region inhabited by the deep-sea fauna. Beebe's and Barton's recorded observations showed that the creatures peculiar to the deep sea are met with between an upper limit of 200 to 400 metres below the surface and the lowest depths of the oceans. A few figures may help us to realize the vast extent of the deep-sea region. The total surface of the seas amounts to some 361·5 million square kilometres, or 70·8 per cent of the earth's surface. The various deep-sea zones have the following proportions of the total expanse of the seas:

TABLE 2

The deep-sea zones of the oceans: their extent and the proportion of the whole surface of the earth that is covered by the sea.

Depth of zones in metres	*Extent of zones, in million square kilometres*	*Percentage of the total surface of the sea*
0– 200	2·74	7·6
200–1000	15·5	4·3
1000–2000	15·2	4·2
2000–3000	24·5	6·8
3000–4000	70·8	19·6
4000–5000	119·1	33
5000–6000	84·1	23·5
6000–7000	4	1·1
over 7000	0·4	0·1

If we take 200 metres below the surface as the upper limit of the habitat of the deep-sea fauna, we find that the surface of the deep-sea region with its strange creatures and its faint light or complete darkness lies beneath 92·4 per cent of the total surface of the sea; the superficial extent of the deep-sea regions is thus 65·4 per cent, or just under two-thirds of the total surface of the globe. These figures indicate the almost inconceivably vast extent of the habitation of the deep-sea creatures, which is not simply a surface one like the much smaller biotope of the dwellers on land, but is three-dimensional (Fig. 2). In addition to this, the unique character and the monotonous uniformity of the conditions of existence it affords put it beyond comparison with any other biotope on this earth.

In view of this it is not surprising that until about a hundred years ago it was supposed that there was nothing living to be found at any lower level than some 500 yards below the surface of the sea. Such was the purport of the "abyss" theory of the Scottish naturalist Edward Forbes. This theory was definitely disproved when in 1860 the cable between Sardinia and North Africa, laid three years earlier, was lifted. It was found that many species of animals had settled on it at spots where it had lain 2000 yards below the surface, so that they must have been able to live at that depth. Under the influence of this and other discoveries, another Scottish naturalist, Charles (later Sir Charles) Wyville Thomson, devoted himself to deep-sea research. He directed the first and one of the most important deep-sea expeditions ever undertaken, working in all the oceans from 1872 to 1876, for which H.M.S. *Challenger* was fitted out. This expedition was mainly concerned with the study of the fauna of the deep sea. The same purpose was served, with special attention to certain problems and objectives, by the great expeditions of the German ship *Valdivia* in 1898–99, directed by Carl Chun, and the Dutch ship *Siboga* in 1899–1900, directed by Max Weber. The scientific results of the *Challenger* Expedition were published in fifty fat quarto volumes, those of the *Siboga* Expedition in more than sixty volumes, and those of the *Valdivia* Expedition in twenty-four.

Many other deep-sea research expeditions have been carried out, by the United States, by France, Italy, Belgium, Norway, Denmark, Austria, and India. Special mention should be made, in view of their importance, of the research expedition of the Norwegian ship *Michael Sars* in the North Atlantic; of that of the Danish ship *Dana*, directed by Johannes Schmidt, which discovered the spawning-beds of the fresh-water eel; and of the oceanographic and deep-sea researches, continued through many years, of Prince Albert I of Monaco in his yachts *Hirondelle* and *Princesse Alice;* the results of these expeditions are also to be found in long series of published volumes. Most important of all for the student of the special conditions of existence in the deep sea, and of the biological bases of the varying density of distribution of the deep-sea fauna in the different latitudes, were the expeditions of the German ships *National*, *Gauss*, *Planet*, *Möve*, *Deutschland*, and *Meteor*, concerned with quantitative estimates of the plankton and with the connexion between the presence of its diminutive organisms and the chemical, physical, and bacteriological conditions and the ocean currents. The objectives and methods of these most fruitful researches are the outcome of the fertile initiative of Victor Hensen, of the University of Kiel, who directed this Plankton Expedition.

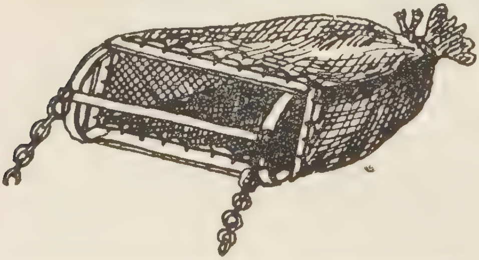


FIG. 18.—Dredge for catching animals on the floor of the ocean.

Of the manifold and complicated devices and appliances used by the expeditions for the capture of deep-sea creatures—to say nothing of those for the investigation of other oceanographic and deep-sea problems—we will consider only the nets. They are of fundamentally simple construction. For the capture for investigation of the benthal fauna, the creatures living actually on the bed of the ocean, a dredge is employed (Fig. 18). It consists of a strong and heavy metal frame from which hangs a fairly coarse-meshed net.

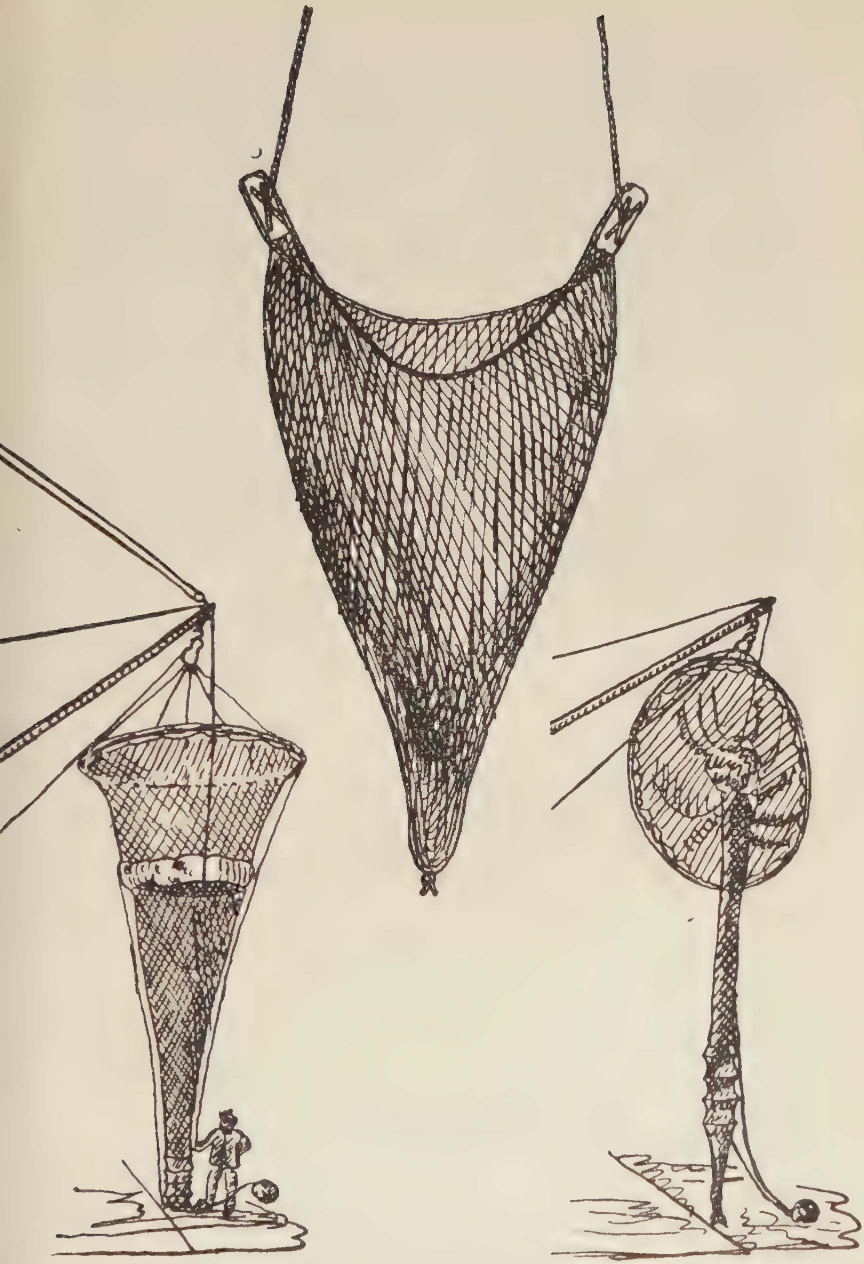


FIG. 19.—Closing net of the Norwegian deep-sea research ship *Michael Sars*, open and closed. In middle of page, an "otter" tow-net.

The frame being heavy, even creatures that have grown firmly attached to the substratum can be scraped up by this dredge. It will not catch small creatures—or very large ones, as the frame cannot have a length exceeding 2 metres (6 feet 6 inches).

For fishing at all depths, down to the bottom, though without making sure of the creatures attached to the substratum, a trawl is used, either a beam or an otter trawl (Fig. 19). It has not a frame like a dredge, but is held open either by a beam or else by the pressure of the water against two plates fixed in a particular way to the towing hawser. The beam trawl can be used with a breadth of opening up to about 15 metres (50 feet); the otter trawl is used with an opening either 20 or 26 metres wide and 40 metres long.

All these nets have the disadvantage that after use at a particular depth they are liable to take in further creatures as they are hauled up, so that there can be no certainty that the contents of the nets belong to the region fished. This disadvantage is avoided by using

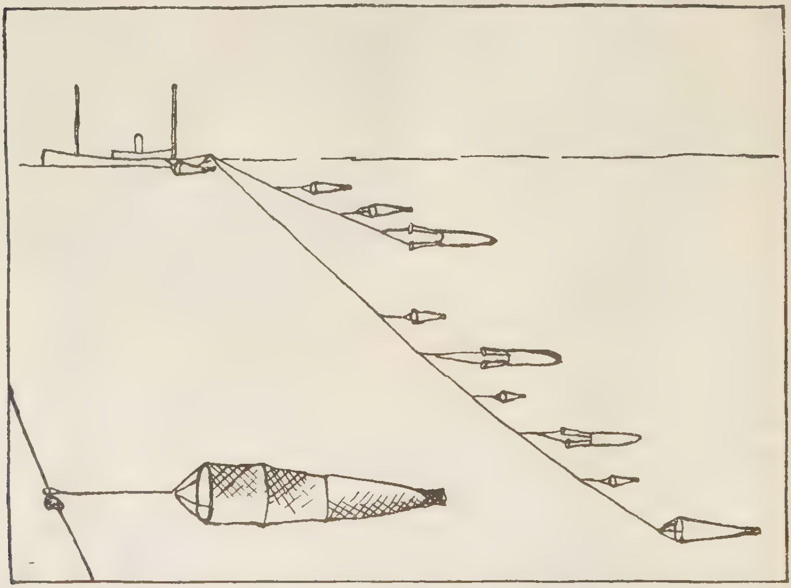


Fig. 20.—The Norwegian deep-sea research ship *Michael Sars*, with set of trawls at intervals down to 3000 metres.

ring nets, kept open by a ring 4 metres wide and 10 or 12 metres long (Fig. 19); the opening can be closed by means of a simple device when the net is being hauled up. These nets are mainly used as vertical nets for fishing in zones of quite definite depth. Another method which has been successful in establishing the depth at which marine creatures prefer to stay consists in the simultaneous use of a series of nets underneath one another on the same towrope (Fig. 20). If these are used for some hours and a particular species of fish or crustacean is not found at all, or scarcely at all, in any nets above 300 and below 600 metres' depth, but is brought up in quantities in nets placed at depths of 400 and 500 metres, it may be inferred that the species in question prefers a depth of 400 to 500 metres below the surface of the sea.

Similar to the ring-closing nets, because they, too, are held open by a ring-shaped bail, and end in a point, but smaller and handier, are the plankton nets, of silk netting of various meshes, for catching the very small creatures of the plankton; most of these nets end in a metal or glass bucket, in which the tiniest organisms, often very delicate, collect as the net is lifted, and are thus saved from exposure to the air.

CHAPTER V

THE FOOD OF THE DEEP-SEA FAUNA

Plants as the first condition for all animal life in the deep sea – The plankton as a community of most small animals floating in the water – Conditions of floating and aids to it – The viscosity of the water – The ocean plants – Animals' appendages that help to solve an important question – The nannoplankton – The food chain in the ocean – The inclusion of the deep-sea fauna in that chain.

Deep-sea animal life shows various special features in its presence and distribution; but before entering into these we must ask ourselves, on what does the deep-sea fauna live? As has been said above, all animal life on this earth depends on the existence of plants; for only plants can draw sustenance from inorganic material, from lifeless Nature, while animals must have organic food, either plant or animal. Thus plants form the indispensable basis of all animal life; but plants in turn, as we have said, depend for their existence—for their capacity to draw from the carbon dioxide contained in air and water the carbon they need for building up the carbohydrates that are the stuff of their cells—on light. So we must not expect to find plants of any sort in the deep sea, and, in fact, they are not to be found there.

We have seen from the descriptions and drawings already given that in the deep sea there are big creatures that live by preying on other animals, and others that live more unexcitingly, grazing on the diminutive creatures in the water, the plankton. The plankton consists of minute and even microscopic creatures, floating in the water and at the mercy of the currents, though in most cases with some small capacity of independent movement. This community of small animals of the sea may be caught with fine-meshed nets, and proves on examination to consist of the most various and curious creatures.

Common to all of them is the capacity to float in the water, and most of them are specially formed or equipped to facilitate floating on or in the water (Figs. 5, 21). As a rule their capacity to float is assured by a specific gravity almost the same as that of the water. Floating is often aided by the gelatinous, water-filled structure of the tissues, as in the jellyfish, the salps, and the swimming worms; particularly in the deep sea we find this feature also in more highly developed animals such as the squids and the true fishes, especially in the young forms. Marine animals may be 99 per cent water, so that they can obviously float almost without effort. Others possess gas chambers or gas bladders, and can rise or sink by increasing or diminishing the quantity or the pressure of the gas in them; this faculty is possessed especially by many of the Portuguese men-o'-war described above. Other plankton organisms reduce their specific gravity and float by means of pockets of oil, big or little, within their body, oil being, of course, lighter than water. These pockets of oil are familiar especially in the eggs of many fishes, whose spawn therefore never sinks to the bottom, and also in quite young fishes, which, owing to their diminutiveness and their small power of swimming, are counted among the plankton; we find them also in the tiny unicellular Radiolaria, and in many planktonic crustaceans.

An expedient of another sort is connected with the resistance offered by the water to all bodies moving in it. We feel the resistance when we swim or row in it. For slowly sinking bodies the resistance of the water consists mainly in the adhesive tendency of tiny particles of water; this tendency is called the viscosity of the water; it can be measured, and is less in warm water than in cold. The more outspread or branching is the form of a plankton animal, the more particles of water the creature has to force apart in slowly sinking, and the greater is the resistance to its sinking that is offered by the water. In these circumstances we can see the biological importance of all the extensions, often very strange, of the appendages, the long,

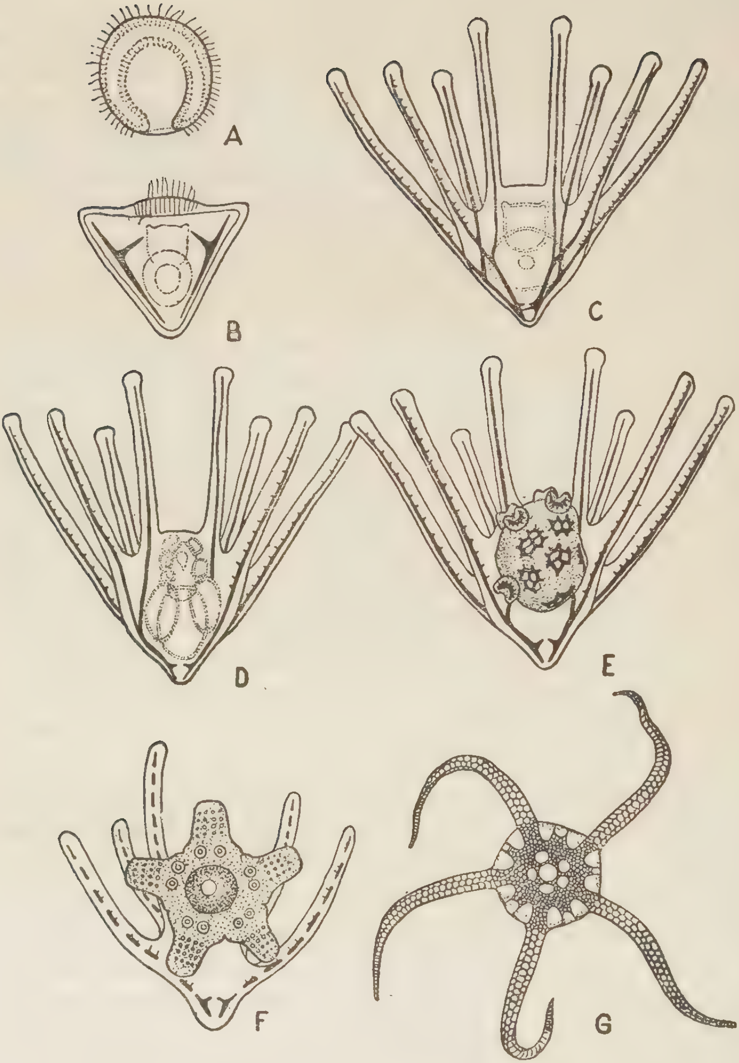


FIG. 21.—Development of a brittle star (*Ophiuroidea*). A to E: Larvae of different ages (C to E the co-called "Pluteus" larvae). F: Pluteus larva and the developing brittle star. G: the fully formed animal. A to F greatly enlarged.

often feathery lashes and brushes, the delicate spikes and pegs, found on the many plankton organisms (Fig. 5, B, D): these increase the resistance of the water and so facilitate floating or suspension. And the fact that warm water is less viscous than cold water explains the greater frequency of these flotation devices in tropical waters.

Thus it is the plankton organisms that are the food of the "fodder" fishes. Very many of these organisms are unicellular animals, only just visible or quite invisible with the naked eye. Among them the many species of Radiolaria (Fig. 23, M, N) are especially noted for their wonderful variety and delicacy of form. Their shell is of strontium silicate or sulphate, enclosing the protoplasm of their single cell. Then there are the jellyfishes, the Portuguese men-o'-war, and the sea gooseberries, the sea urchins, starfishes, and sea cucumbers, which belong to the plankton. There are also the pteropods, the worms, the immense shoals of small copepods, ostracods, and also the rather larger schizopod crustaceans and some of the prawns, and the strange salps, and finally all the countless larvae and young of the worms, gastropod molluscs, crustaceans, and other marine animals (Figs. 5, E, F; 6, H, J; 21); all these are plankton. Here, too, the larger animals swallow the smaller, and so down to the unicellular ones.

Among the smallest, the unicellular plankton organisms, we also find plants (Fig. 23), organisms with the chlorophyll, the green colouring matter with the aid of which, in the presence of light, they draw from the carbon dioxide contained in the atmosphere or the water the carbon they need for their growth. In these we meet with "autotrophic" beings which can absorb inorganic matter, the product, that is, of lifeless Nature, and through that faculty form the foundation of the existence of all the complicated animal life of the sea. But these plants form only a small proportion of the plankton we fish up, and they consist only of minute unicellular forms: how can it be that the manifold animal life in the ocean depends on this as its ultimate food basis?

Are there, then, in the sea no more highly developed plants of the kind we know on the dry land, with flowers, fruits, and leaves, each plant consisting of innumerable cells? No, these are not to be found in the sea. All higher plants, such as are represented by the many striking members of the flora of the dry land, are absent from the sea, all plants marked by the differentiation between roots, stem, and genuine leaves. In the sea are only the most rudimentarily organized plants, apart from the bacteria—which are only subsidiary elements of plant life—the flagellates, diatoms, and blue, green, and red algae. Very many of them are unicellular, appearing in any case in colonies and almost always microscopic. To these belong those which we found in the ocean plankton. Among the blue, green, and red algae are counted the seaweeds of our coasts, which with their multicellular stems flowing in the water not seldom reach a length of dozens of yards. But of these handsome though rudimentarily organized plants, apart from those actually on the sea-shore, which is their natural habitat, there are only two species in existence, both living on the surface of the high seas, especially in the famous Sargasso Sea between the Azores and the West Indies. Except for these the plant plankton is made up entirely of unicellular plant forms, such as those already mentioned. To repeat our question, can these organisms, which do not even seem frequent in our hauls in comparison with the masses of the animal plankton, really be the foundation of the whole food supply of the ocean fauna?

To help us to answer this question, let us examine the contents of the stomach of, say, a small crustacean such as a copepod, or ostracod, or, better still, one of the tailed tunicates, the Appendicularia (Fig. 22). These we often find in enormous quantities in the ocean plankton: they play an important part as food for large marine animals. These very Appendicularia, only a few millimetres or at most one or two centimetres long, just suit our present purpose.

The Appendicularia, like the salps, belong to the Tunicata, a class which, owing to the possession of a "chord", an elastic gelatinous supporting rod under the main nerve fibre at their back, stands nearest to the direct ancestor of the vertebrates and must be regarded as a degenerate collateral branch of them; for the "chord" generally possessed by the tunicates represents the origin of the spine in vertebrates; but the Tunicata have this chord only in the larva or the young animal, losing it in the adult stage: to this loss the Appendicularia are the only exception. The Tunicata have a further special feature, from which they take their name, a so-called tunic that covers their body; it is separated from the surface cells of the body, and consists of a material very similar to plant cellulose, not found anywhere else in the animal kingdom. This tunic surrounds the appendicularian like a shell; owing to its high water content it is so delicate that it almost melts away; it is rather more than half the size of a man's hand, so that it forms a protection for the tiny creatures, since in any emergency they can slip out of it. They then form a new one as quickly as they can. The tunic serves them also, with the aid of a complicated mechanism for catching and holding, as a filter for the minute marine organisms on which the appendicularian feeds.

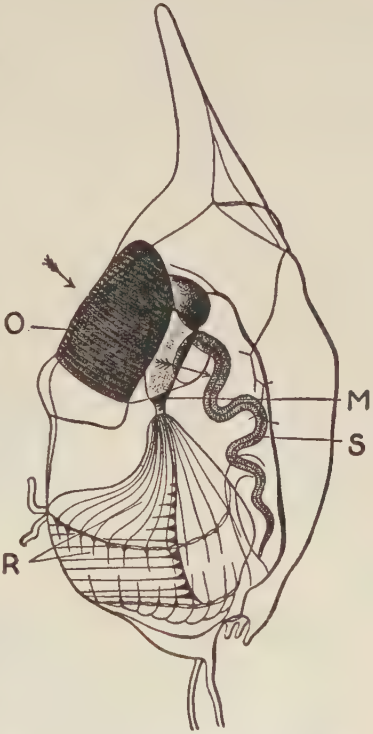


FIG. 22.—The tailed tunicate or appendicularian *Oikopleura albicans* in its house; side view. O: Opening of the house with filter plate. R: Flushing and filtering mechanism. M: Mouth-opening. The arrows show the direction of the stream of water. Cf. Fig. 96. 4 times natural size.

And in the stomachs of these tailed tunicates, and also in those of the smallest crustaceans, the pteropods and other plankton animals, we find countless minute unicellular creatures, mainly plants (Fig. 23). We found none of them in our plankton nets: it is a technical impossibility to produce nets fine enough to catch this dwarf plankton, the scientists' "nannoplankton". But we can see

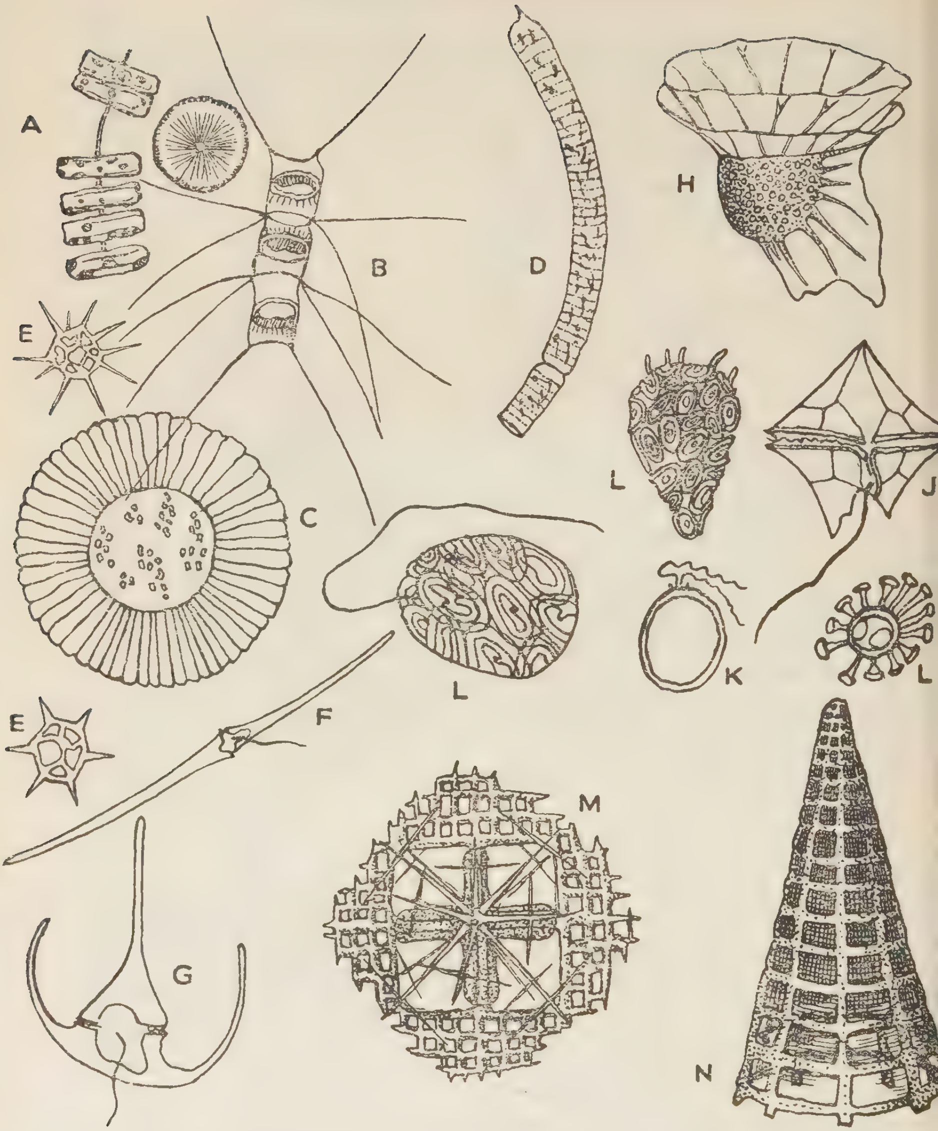


FIG. 23.—Unicellular plankton organisms of the oceans. A to D: siliceous algae (diatoms). E: Siliceous-shelled Silicoflagellates. F to K: Armed flagellates (Dinoflagellates), genus *Ceratium.* (F, G, Ornithocercus; H, Peridinium; J and K, a shell-less form.) L: Calcareous flagellates (Coccolithophoridae). M and N: Radiolaria: M, *Lithoptera darwini;* N, *Cinclopyramis infundibulum.*

at once how the tailed tunicates catch them for their food when we compare a drawing of their filter-net, greatly enlarged, with the meshes of our finest netting under similar magnification. Most of the minute plant organisms of the nannoplankton that pass through that filter-net and are retained, pass in and out of the finest netting. Scientists became acquainted with the multitudinous forms and individuals of the nannoplankton only through the much more perfect retaining filter of the appendicularians and other minute marine animals, such as the small crustaceans and pteropods. Later it became possible by other means, especially by the use of centrifuges, to pursue closer research. In the centrifuge small vessels filled with sea water are rotated so quickly that everything in the water that is in the least degree heavier than water is thrown against the bottom of the glass containers and can be microscopically examined, compared, and counted.

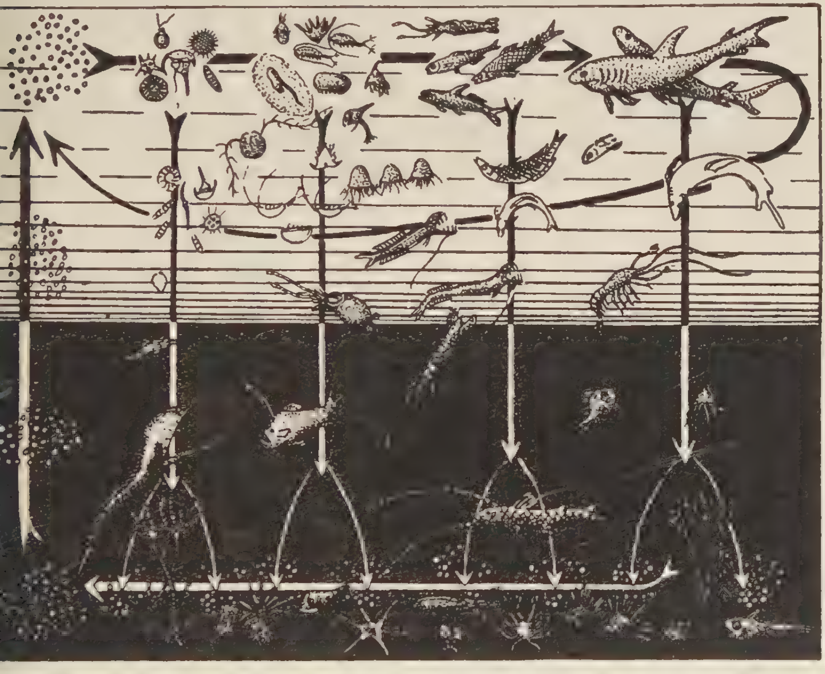
Most of the creatures of the nannoplankton belong to the flagellates and are found in extraordinary masses in the sea water; they form the actual basis of the food supply of all animal life in the ocean, the basis for which we have been looking.

The operation of the autotrophic faculty of plants, that is to say, the faculty of consuming and assimilating inorganic matter, requires, however, as we said, the presence of light. The minute plants of the plankton can therefore only live in the sunlit upper layers of the sea. We have spoken of forms that have special need of light and of others living in twilight, living perhaps at a depth of 50 metres and in many places very prolific at that depth; but plants are not to be found at much greater depths and not at all in the lightless regions of the deep sea. From what has been said above we may picture the course of existence in the upper layers of the sea. The dwarf plant-plankton serves the larger plankton animals, which are able to filter it from the water, as food; these, however, themselves multitudinous, become the food of larger creatures of the sea, from small fishes to gigantic whales. And in this community the countless predatory fishes, the squids, and the rest, find their allotted meal. Immense numbers, however, of these different creatures perish without falling victim to any enemy. Often, as among the unicellular organisms and other creatures of the plankton, they escape because their life is too short; or they are carried by currents into water that is too warm or too cold, and so lose their life; or they may have no actual enemy. In all such cases they sooner or later decompose. In the water as on land their decomposition is due to bacteria, the smallest of all creatures, which cannot properly be included in either the plant or the animal kingdom. Without them the decay and decomposition of organic matter cannot usually take place; but we will not enter here into the complicated chemical processes resulting from the activity of bacteria. That activity transforms the complex organic compounds of which plants and animals mainly consist into simpler ones, and ultimately into the inorganic matter from which plants alone can directly draw their subsistence. This completes the vital chain of which all creatures of the sea are links.

But how are the deep-sea animals included in this vital chain? For plants can only assimilate inorganic substances, and convert them into organic, in the presence of light, and animals can only feed on organic substances, so that it might be supposed that the closing of the vital chain of nourishment is bound up with the sunlit upper layers of the water. That is indeed so, but the animals of the deep sea are nevertheless brought into the food chain.

The process of bacterial decomposition of the small and large creatures of the sea takes a long time, during which the dead bodies slowly sink, together with the remains of the meals of predatory creatures near the surface, finally reaching the lowest depths of the ocean. We may picture a sort of continual raining down of small and large pieces of organic matter into the depths, where the creatures living on the floor of the ocean, and the animal plankton of the deep sea, live on this overflow from the upper layers of the water. The deep-sea animals thus fed are pursued by large numbers of predatory creatures, large and small, in most cases powerfully equipped for hunting, with some of which among the fishes and squids we have already made some acquaintance.

But if the sinking organic matter, when it reaches the bottom, is not there consumed by the deep-sea creatures, it is then further reduced by the bacteria that exist in the depths to the simpler inorganic substances, mostly compounds of nitrogen and phosphorus, which with carbon make up its main components. Obviously these components can no longer be made use of by animals; nevertheless they are not lost to the chain of nutrition in the sea. They accumulate in the depths. In certain parts of the ocean they



IG. 24.—Plan of the chain of nitrogenous and phosphorous nutrient salts in the ocean, shown
y means of small circles or white points. The salts are consumed by the organisms of the plant
annoplankton and the links of the "animal food chain" associated with it in the surface layer
f the ocean. Some salts are liberated in the ocean by the decomposition of the bodies of animals
nd of remains of the meals of predatory animals (chain of arrows above); those not consumed
each the depths (downward pointing arrows) with the sinking matter that is the basis of the
od of the deep-sea animals. The nutrient salts liberated by the complete decomposition of the
nking matter cannot, however, be consumed in the depths owing to the absence of plants;
e decomposition is completed in the depths and the resultant nutrient salts are brought by upward
currents (arrow on the left) back to the upper water.

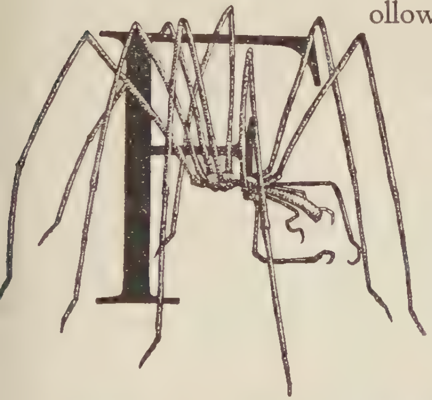
are then, through the agency of vertical upward currents, carried back to the upper layers, where this nutrient material from the deep once more supports a particularly profuse population of the tiniest plants, and so also the plankton and other animals feeding on them (Fig. 24).

Since the deep-sea fauna depends ultimately for its subsistence, in the way described, on the remains of the surplus of the upper regions of the ocean, it becomes clear that in the depths in general there can be no excessive food supply, and, indeed, there will be a real scarcity. In this we must find the main reason for the sparse settlement of the deep sea, for the almost constant scarcity of all the species of animals living there, and also the main reason for the wildly grotesque and almost uncanny equipment with which especially its beasts of prey secure their victims.

CHAPTER VI

THE INORGANIC FOODSTUFFS IN THE SEA

The salinity of sea-water – Nitrates and phosphates, the principal nutrient salts – Their limited and varying presence in the sea – Liebig's "minimum law" – The deep sea as source and reservoir for the food-salt requirements of life in the ocean – The causes of the rise of water from the depths to the surface – Carbon dioxide and oxygen in the sea



Following our account of the sources of food for deep-sea animals and of the closed circle of food-supply in the ocean, we need briefly to consider the most important of the inorganic foodstuffs and their distribution and origin in the ocean. It is from these, of course, that plants build up their organic substance, so providing the first condition for animal life; this makes clear the important part played by these inorganic materials in determining the wealth or poverty of the ocean in living beings.

This is mainly a question of carbon, oxygen, and simple nutrient salts. Sea-water, unlike fresh water, contains a number of different salts. The total quantity of salts in a given weight of sea-water is called its salinity, and the average salinity is 3·5 per cent. A kilogram of sea-water (about a litre) contains salts approximately as shown in the table on page 66.

The figures given are only approximate, for, in addition to the substances shown, sea-water contains numerous other solid constituents, mainly salts, but only the smallest traces of each. The salts

TABLE 3

The principal salts in the sea: weight and proportion of the total solid components of a litre of sea-water

	Grammes	*Per cent*
Sodium chloride (cooking salt)	27·21	77·8
Magnesium chloride	3·81	10·9
Magnesium sulphate	1·66	4·7
Calcium sulphate	1·26	3·6
Potassium sulphate	0·86	2·5
Calcium carbonate	0·12	0·3
Magnesium bromide	0·08	0·2
	35·00	100

listed above, however, which virtually make up the actual salinity of sea-water, are scarcely used at all by plants in building up their structure. On them the extent of the development of plant and animal life in the sea never depends. (For the rest, the salinity of the oceans varies only within quite narrow limits.) The principal nutrient salts for plants, and so for the plants of the ocean, are compounds of nitrogen and of phosphorus; these are present in the sea as dissolved substances. As we said, in comparison with the salts mentioned in the table these compounds are present in a sample litre of sea-water only in minute traces. Among the numerous "trace elements" known in the sea various chemical compounds of nitrogen and phosphorus (and, incidentally, silicon or silicic acid) are the very ones with the most variable concentrations in sea-water. Nitrogen is present in quantities varying between 0·01 and 0·7 milligrams to the kilogram (litre), and phosphorus in quantities between 0·001 and 0·1 milligrams to the kilogram (litre), of sea-water. Thus, these nutrient salts, so indispensable for plant life in the oceans, are present in relatively minute quantities, though, owing to the vast extent of the oceans, their absolute quantity is enormous; and in view of the variability of these quantities there are some "bottle-necks" for the development of plant life in the ocean; this we find confirmed by the "minimum law" enumerated in the last century by the famous German chemist Liebig. This law states that chemical and also biological transformations or processes are limited in their scale by the lowest quantities or dimensions present of a component necessary to them. If, for instance, nitrogen and phosphorus are present in sea-water in such varying proportions, the quantity of the plants in the ocean, and especially of the tiny unicellular plants of the nannoplankton, will vary to the same extent. On the quantity, however, of the nannoplankton depends that of the rather larger plankton animals that feed on the plant plankton; and on this depends in turn the quantity of the larger creatures that live on the plankton animals, and on this the number of predatory animals that live on the eaters of plankton animals. In accordance with what we further saw in regard to the food of the deep-sea animals, which depend on the foodstuffs sinking from the upper layers of the water, the ampler or scarcer means of life in the deep sea must depend on the quantity of living beings in the upper layers of the water, and so ultimately on their content of phosphates and nitrates (phosphorus and nitrogen salts).

This dependence does in fact exist, as is shown by our diagrams of the phosphate content of the surface water and the varying quantities of plankton organisms on the surface in comparison with those at 2000 metres' depth. But on what do the great fluctuations in the phosphorus and nitrogen salts in the sea, scarce as they are, themselves depend?

The deep sea has shown itself to be the source and the reservoir of the nutrient salts essential to life in the ocean. There the phosphorus and nitrogen compounds accumulate, as the product of the action of bacteria, as mentioned above, on the organic matter sinking from the surface water and not consumed by animals. In addition to this, such salts exist on the floor of the ocean as on land, and are dissolved in the water. They accumulate in the depths because, in the absence of light, there are no plants to consume them. Investigations have shown the abundance of nutrient salts in the deep sea; our diagrams show clearly the rapid increase in phosphates

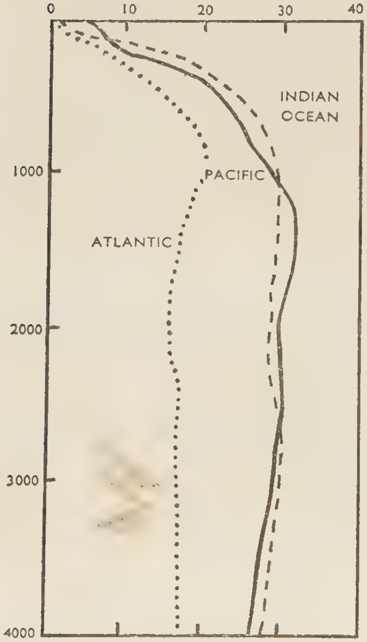


Fig. 25.—Diagram showing the average phosphorus content in the oceans down to 4000 metres; the curves give the content in thousandths of a milligram per litre of sea-water.

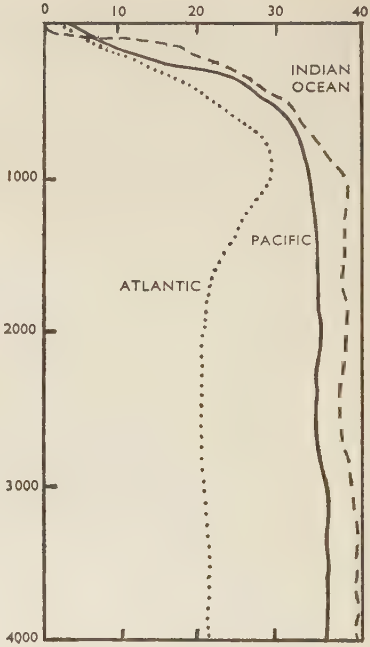


Fig. 26.—Diagram showing the average nitrogen content in the oceans down to 4000 metres; the curves give the content in thousandths of a milligram per litre of sea-water.

and nitrates between the surface of the sea and 1000 metres down; after that there is little change. We will not discuss here why the content falls at greater depths, though never to the surface minimum.

The greater or lesser abundance of phosphates and nitrates in the upper water, where they can be utilized by plants, must therefore depend largely on some important means of replacement. This is provided by ascending currents. Such currents exist, as has been said above, in various regions.

There are four main causes, in various parts of the earth, of the vertical currents which bring to the surface the water in the depths with its wealth of nutrient salts. At the Poles the cold surface water sinks and so drives up the water in the depths, which is less cold and therefore of less specific gravity. This cause is of special importance in producing the constant rise of deep-sea water rich in nutrient salts in the southern ocean bordering the polar sea, and to it is due the enormous animal population of these seas. Another important cause of the rise of water from the depths is the strong south-east trade wind off the west coast of Africa, blowing almost constantly. This trade wind, together with the effects of the rotation of the earth, produces a permanent westward current of the surface water in the South Atlantic. As there can be no replacing flow from the east, water is sucked up, as it were, from below to replace the loss from the westward current. These two phenomena are the main causes of the wealth of nutrient salts in the upper waters of the central and southern Atlantic. The diagrams in figures 27-30 show how the difference in the concentration of nutrient salts is exactly paralleled by the difference in the profusion of plankton organisms at the surface, and also at a depth of 2000 metres.

A third cause of the rise of water from the depths of the ocean, with its high nutrient content, is the collision of different currents in the sea at different points. Under certain conditions such ocean currents from different quarters may, as it were, be drawn away from each other after colliding, so that a sort of vacuum is produced between them. This vacuum can only be filled by water rising from below. This phenomenon can be well observed at the meeting of the warm Gulf Stream with the cold East Greenland current off Iceland, and it is found in a rather different but comparable form north-east of Japan at the meeting of a cold northern current, the Oya Shio, with a warm southern one, the Kuro Shio: in both cases, for the reasons mentioned, the rise of water from the depths, rich in nutriment, results, and is itself the cause of the immense yield of the fishing-grounds in those regions.

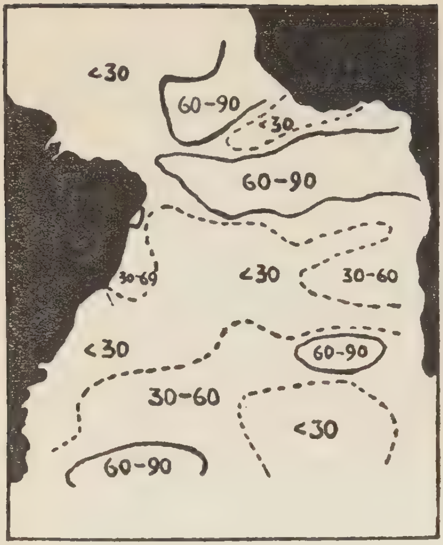


FIG. 27.—Plankton distribution in the South Atlantic at a depth of 2000 metres. The figures give the number of plankton creatures in the regions shown.

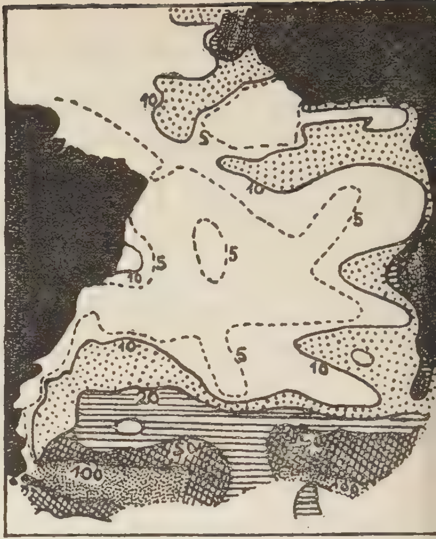


FIG. 28.—Density of the population of plankton creatures in the South Atlantic, from the surface to 50 metres down. Black: the continents. The figures by the marginal lines give the number of thousands of individual creatures per litre of sea-water.

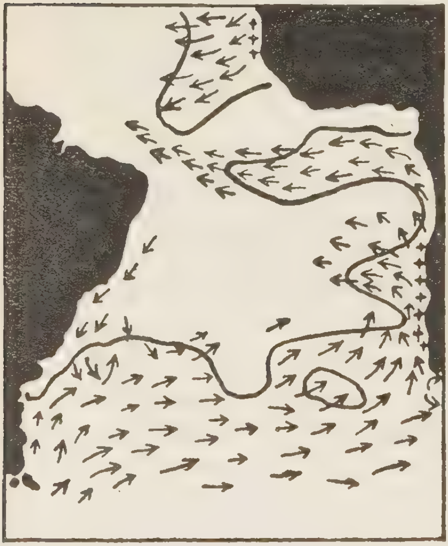


FIG. 29.—The arrows show the surface currents in the regions of the South Atlantic with more than 7000 cells of plankton per litre of water (from the surface to 50 metres down). The small crosses off the African coast show the regions with water rising from the depths.

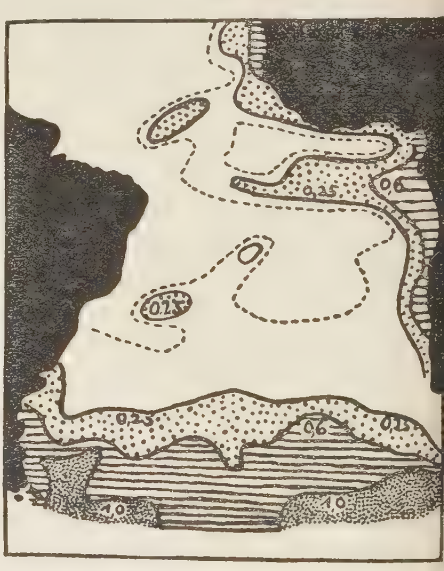


FIG. 30.—Distribution of phosphates in the surface water of the South Atlantic. Black: the continents. The figures by the marginal lines give the content of P_2O_5 in milligrams to the cubic metre of water.

Finally, in the higher latitudes the seasonal change of temperature produces an interchange between the surface water and the water in the depths; for when winter comes the surface water gradually cools. Since the spring it has given up the whole of its nutriment to the masses of plankton creatures that developed as the water warmed. Now, with the coming of winter, it gradually cools until it is colder than the water beneath it—and therefore of greater specific gravity.

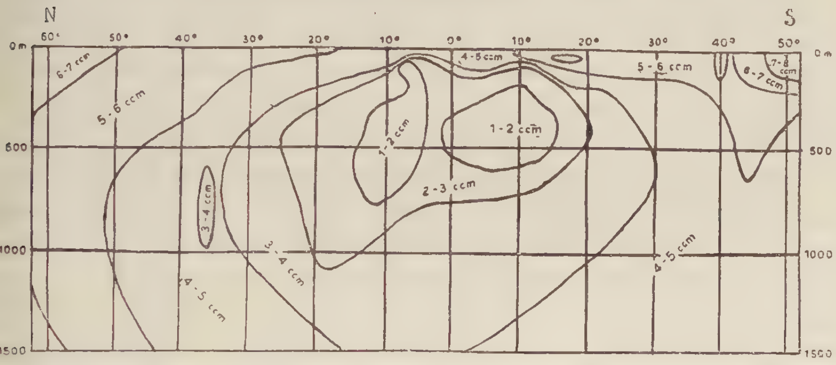


FIG. 31.—Cross section of the Atlantic between 60° N. and 50° S. and down to 1500 metres, showing the quantities of oxygen in the ocean, which vary between 1–2 and 7–8 cubic centimetres in the litre of sea-water.

Then it sinks, and the lower layers rise, with their wealth of nutrient salts on which the plants of the nannoplankton feed when the water warms again.

In addition to nutrient salts we mentioned carbon dioxide and oxygen as indispensable to the existence of plant and animal life in the sea, carbon dioxide as the direct source of carbon for the structure of plants, and oxygen for the part it plays in all processes of chemical assimilation of food (metabolism), which are almost all, of course, processes of combustion and can only take place in the presence of oxygen. Animals and plants living on land draw this vital gas from the atmosphere. But sea-water always and everywhere holds carbon dioxide and oxygen in solution, mainly drawn from the air. The atmosphere contains 0·03 per cent of carbon dioxide, and this percentage is virtually kept constant by the ocean, which absorbs the atmospheric carbon dioxide in excess of that percentage. The quantities of carbon dioxide (some hundreds of cubic millimetres to the litre) and oxygen (1 to 8 cubic centimetres to the litre) in solution in sea-water vary within wide limits, depending largely on the temperature of the water; at 30° C. the water can absorb only half as much oxygen as at 0° C.

Carbon dioxide and oxygen are everywhere in the sea, even at the greatest depths, in sufficient quantities, though the carbon dioxide content is greater in the cold water in the high latitudes—a further reason for the massive development of animal life observed there, as already mentioned. The oxygen content is exceptionally low in more or less enclosed basins or bays, such as the Black Sea. There the over-development of certain bacteria entirely exhausts the oxygen at considerable depths; as a result free hydrogen sulphide, which is poisonous, comes in solution into the water, so that in the Black Sea there is no animal life below 400 metres.

CHAPTER VII

THE INHABITED REGIONS OF THE DEEP SEA

Mud and ooze – Terrigenous and pelagic sediments – Countless billions of minute creatures that make the floor of the ocean – The red clay – Inhabited deserts at the bottom of the ocean – The pelagic and benthal populations – Bank, slope, and continental shelf – The abyss

The nature of the floor of the ocean determines in some degree the density of the population of marine animals living in the depths, and especially on the ocean floor itself.

Everywhere below about 200 metres the ocean bed consists of mud or ooze; bare rocks are not often found in the depths. But the composition of the mud or ooze varies greatly. Its components are distinguished by an old but still very serviceable division into pelagic and terrigenous sediments, that is to say, those deposited from the sea itself and those coming from the land. The terrigenous sediments are brought down by the breakers and from the rivers, and also by the violent dust storms in some regions of the dry land and from volcanic eruptions. These sediments are generally found near the coast. In the deep sea the principal sediments are known as blue, green, and red mud; in addition to these there are sediments clearly of volcanic origin. The blue mud is much the most generally found; it owes its colour to its content of iron sulphide, arising from the decomposition of organic substances. The colour of the green mud is due to glauconite, a silicic compound of potassium with iron. The red mud is found only off the north-east coast of South America; it owes its colour to mud deposited from the rivers Amazon and Orinoco. The terrigenous coastwise sediments are rich in organic detritus, which can be consumed by the benthal animals that specialize in mud-eating, so that these regions of the sea floor support a rich development of animal life, even where they extend to a great depth.

The pelagic sediments, deposited from the sea itself, generally far from the coasts, are largely the remains of organisms, particularly the inorganic components of silicic or calcareous shells of minute plankton organisms. The principal pelagic sediment is known as Globigerina ooze; it is formed by the shells of Globigerina (Fig. 32), unicellular "root-footed" Rhizopoda belonging to the order of Foraminifera; at about 4000 metres below the surface their calcareous shells form the most widespread deposit on the ocean floor. Then there is Radiolarian ooze (Fig. 33), mainly consisting of the shells of the unicellular Radiolaria; and Pteropod ooze (Fig. 34), made up of shells of pelagic sea-snails (Pteropoda).

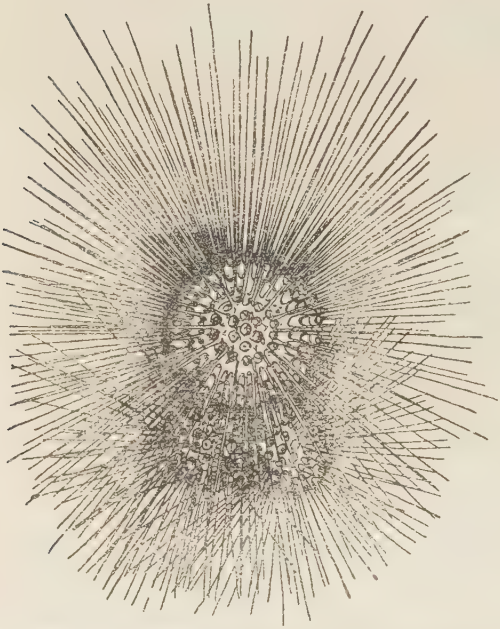
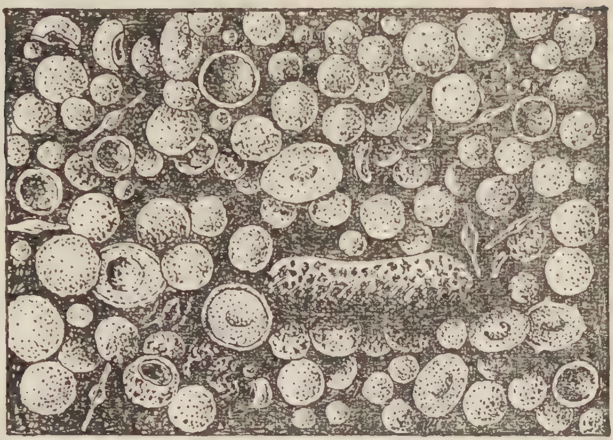


FIG. 32.—Shelled amoebae of the genus *Globigerina*, 100 times natural size.

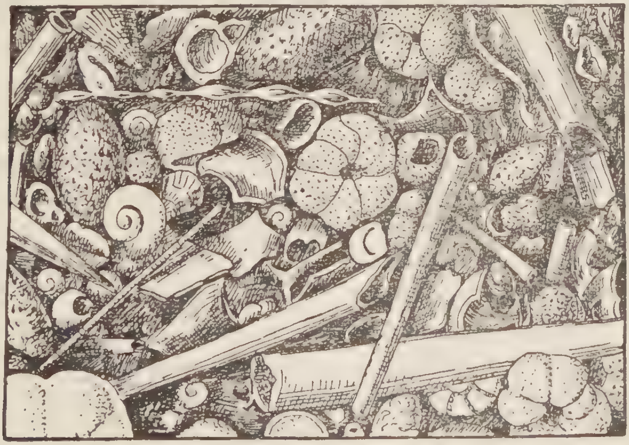
These are all calcareous deposits. Diatom ooze is made up of siliceous shells. The distribution of these sediments is shown in the sketch map, Fig. 35. The study of this distribution has yielded much information, particularly in regard to the geological history of the oceans.

There is a limit, however, to the appearance of these "biogenes" (sediments due to organisms): below 4000 metres the lime content of the deep sea is so low that at that depth calcareous elements, such



G. 33.—Radiolaria oze in the Antarctic, ooo metres down. bout 30 times natural size.

as the shells of most of the minute organisms mentioned, which form the oozes in such inconceivable profusion, are dissolved and disappear. Consequently in these depths there remains only the red clay, the most widespread of all the oceanic deposits. It owes its name to its russet colour; it is rich in quartz substances, and, strangely, in radio-active substances; little is yet known of its origin. It contains very little organic matter, and as below 4000 or 5000 metres very



G. 34.—Pteropod ze, Indian Ocean, o metres. 25 times natural size.

little is left of the "rain" of organic detritus from the upper water, the benthal fauna of the red clay is very sparse. In the region of the red clay, for instance in the middle of the Pacific, there are virtual deserts, with only very occasional traces of organic life. Remarkable features are the rounded lumps, about the size of a man's fist, composed of manganese oxide and iron oxide, which are sometimes found in quantities on the red clay.

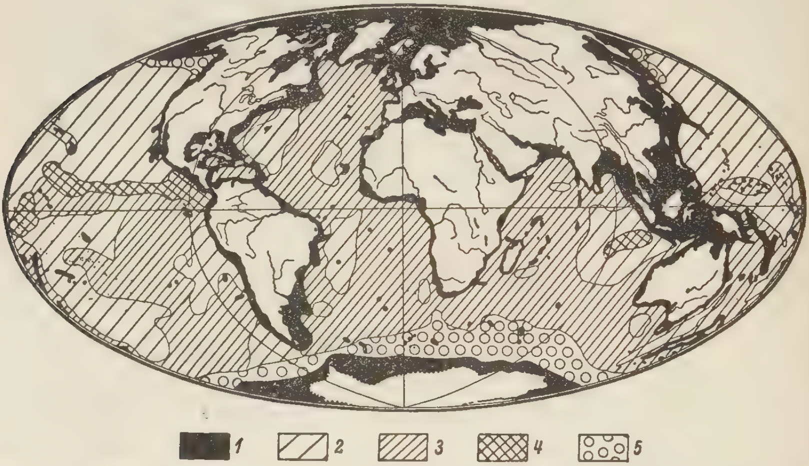


FIG. 35.—Distribution of the principal deposits on the floor of the oceans. 1. Coastal deposits ("littoral" or "terrigenous"). 2. Deep-sea red clay. 3. Globigerina ooze, including the Pteropod ooze. 4. Radiolarian ooze. 5. Diatom ooze.

In spite of the different types of their deposits, the various regions of the deep-sea floor form, on the whole, a uniform ecological province of the deep sea, marked by the predominance of animals more or less tied to the bottom of the ocean, either crawling or sessile. Over against this is the other great ecological province of the deep sea, marked by a totally different population of swimming or drifting creatures, quite independent of the floor of the ocean. The swimming creatures are scientifically grouped as the Nekton; the drifting animals, most of them minute, are the Plankton; there is no sharp dividing line between these two. The animals living on the floor of the ocean are known as the benthal population.

TABLE 4

Distribution of the various types of sea floor, with the areas they cover, according to the information accumulated by the *Challenger* Expedition

Name of the type of deposit	*Area covered (square kilometres)*	*Percentage of the earth's surface*	*Percentage of the floor of the sea*
Globigerina ooze	128,000,000	25·2	37·4
Pteropod ooze	1,040,000	0·2	0·3
Radiolarian ooze	5,930,000	1·1	1·6
Diatom ooze	28,200,000	5·5	8·2
Blue mud	37,500,000	7·3	10·8
Green mud	2,200,000	0·4	0·6
Red mud	259,000	0·05	0·07
Red clay	133,000,000	26·2	38·8
Calcareous sands	6,620,000	1·3	1·8
Volcanic sands	1,550,000	0·3	0·43
Total	—	67·55	100·0

A different sort of classification of the population of the ocean is based on the vertical divisions of the ocean floor and the different levels preferred by the marine creatures. Down to about 200 metres the bottom has a relatively gentle gradient. This is the coastal region, the "littoral", known to fishermen as "banks" and to oceanographers as the continental shelf; it has its own characteristic population of benthal and pelagic (swimming or drifting) animals. Below 200 metres the bottom generally falls more steeply. This region is known as the continental slope. At about 2000 metres the continental slope merges into the depths, the so-called "abyss" (Figs. 36, 132). The Abyssos was the lowest part of the underworld in Greek mythology. Each of these regions has its characteristic animal population. We are less interested here in that of the coastal waters and the sunlit upper water of the high seas; our concern is with the life in the actual depths. We saw that the deep sea begins at a depth of 200 to 400 metres, where the light is reduced to a dark grey and the self-lit creatures of the depths reach their upper limit.

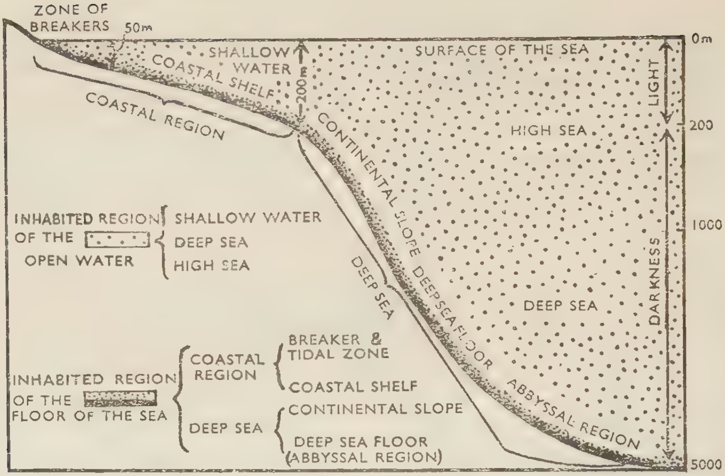


FIG. 36.—Diagram showing the living spaces in the ocean.

In the deep sea again we may also distinguish between the animal population of the continental slope, from 200 or 400 to 1000 or 1500 metres below the surface, and that of the abyssal region, from 1000 or 1500 metres to the lowest depths. It is to this abyssal region that our description of the monotony of the conditions of existence in the deep sea is most fully applicable—the complete darkness, the almost motionless water, a temperature always below 5° C and generally between 2·5° and 1° C, and food scarcity. To this region is also applicable the distinction between the swimming or drifting "bathypelagic" animals and the "bathybenthal" inhabitants of the floor of the deep ocean.

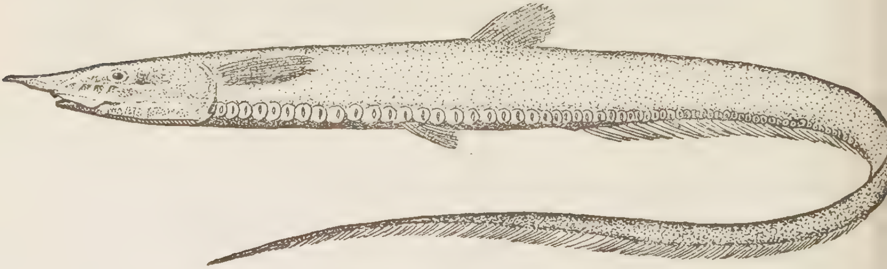
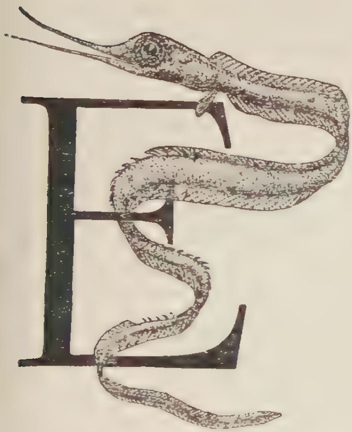


FIG. 37.—The sea-lizard fish *Halosaurus rostratus*. In all oceans, 3000 to 5000 metres. One-third natural size.

CHAPTER VIII

THE ANIMAL WORLD OF THE OCEAN FLOOR

Paucity of living creatures in the abyssal region – Rat tails and sea-lizard fishes – Eelpouts, blenny-like fishes, ophidoid fishes – "Grimaldichthys", a fish from 20,000 feet down – The sessile animals – Echinoderms ("spike-skins") and crabs – Benthal methods of gaining food – The benthal population of the continental slopes – Frilled sharks and bat fishes – Octopods and squids – Nautilus



Everywhere at great depths the floor of the ocean is very sparsely populated. Those great depths of 4000 metres or more, far from the land, are reached by scarcely any of the sinking organic material that may be brought into the sea by rivers or the wind, and such material as may come from the upper water will be so thoroughly disintegrated as to be of no food value for animals. Particularly on the red clay, with its scarcity of organic material, no wealth of animal life can develop. This poverty is clearly revealed by the results of dredging at great depths carried out by the research ships *Challenger*, *Valdivia*, and *Michael Sars*. Each operation of the dredge here mentioned lasted 3½ to 9 hours.

Challenger, dredging at 4800 metres (15,850 feet): yield, shark's teeth, two mussels, shells of deep-sea Cirripedia, crustaceans of the genus *Scalpellum* (Fig. 43).

Challenger, at 5000 metres (16,500 feet): yield, three live mussels and a few mussel shells.

Challenger, at 5000 metres: yield, bits of worms, a Cirripedia, crustaceans of the genus *Scalpellum*, a benthal lizard-fish (*Halosaurus rostratus*, Fig. 37).

Challenger, at 5800 metres (19,000 feet): yield, a sponge, three corals, six sea anemones, a small colony of polyps, two sea lilies (Fig. 44), three stars, a sea urchin, five sea cucumbers (Figs. 42, 128); several worms, seven mussels, and one cephalopod.

Valdivia, at 5250 metres (17,300 feet): yield, a sponge, five polyps, a species of *Cerianthus*, a star, a sea urchin, a sea cucumber.

Michael Sars, at 4700 metres (15,500 feet): yield, some sponges, three sea anemones, some sea cucumbers, two stars, some worms, some sea squirts and moss animalcules (corals), a snail, and two fishes of the benthal genus *Macrurus* (*M. armatus* and *M. brevibarbis*).

Michael Sars, at 5000 metres: yield, a shell of a "paper nautilus" (a species of cuttlefish), an earbone of a whale, two shark's teeth, ten pteropod shells, a polyp stem, an eight-rayed coral, two sea cucumbers, and six fishes of the genera *Alepocephalus*, *Bathymicrops*, *Malacosteus* (Fig. 118), and *Argyropelecus* (Fig. 79) —not all of which, however, live on the bed of the ocean, and the last two are unlikely to live at such a depth: they must have been taken by the dredge (which was not capable of being closed) on its way up.

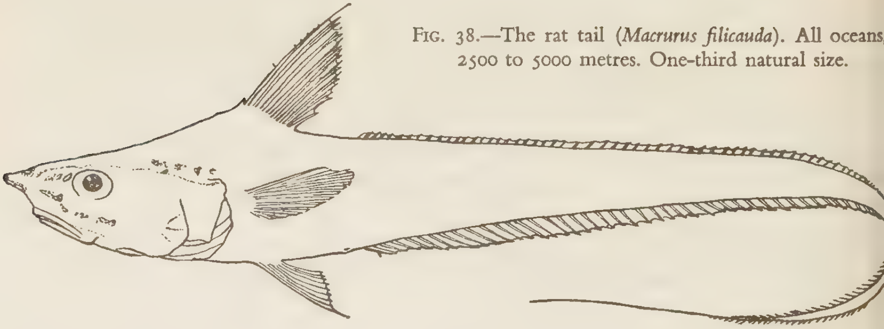


Fig. 38.—The rat tail (*Macrurus filicauda*). All oceans 2500 to 5000 metres. One-third natural size.

The relatively good hauls of the *Michael Sars* are explained mainly by the improved equipment and methods available to it. The *Challenger's* haul was the best known up to that time.

The results of catches made so far seem to show that very few fishes live on the floor of the ocean at depths exceeding some 3500 metres. It seems clear that the floor of the ocean at such depths is the exclusive, or at least the preferred, habitat only of a few species of the rat tails of the genus *Macrurus* (Figs. 38, 130), which are related to the cod-like fishes—the rat tails *M. sclerorhynchus*, *M. armatus*, *M. filicauda*—and of some species of fish of the family of the eelpouts (family Zoarcidae), which in spite of their eel-like appearance are perch-like fishes, and of the closely related families of the blennies and ophidoids (Blenniidae and Ophidiidae); mention should be made of the members of the genus *Lycodes* and of such strange forms as the blind "nose-fish" (*Typhlonus nasus*) or the "spine-fish" (genus *Acanthonus*, Fig. 45). *Grimaldichthys profundissimus*, too, brought up from the greatest depth recorded until lately for a catch of fish, 6000 metres (20,000 feet), probably lives on the bottom of the ocean; it belongs to the Brotulidae, closely related to the eelpouts, the blennies, and the ophidoid fishes. It was one of the deep-sea fishes caught during the many years of oceanographic research carried on by Prince Albert I of Monaco, whose family name was Grimaldi.

Many more species of animals have been found which belong entirely to the benthal population of the greatest depths of the oceans. Many of these species of mussels, worms, polyps, etc., have been found only on one occasion, often only as single specimens. Particularly characteristic of the population of the bottom of the ocean are the many sessile animals, fixed to the bottom either at birth or later in their life. These include sponges, stalked polyps, sea anemones and corals, sea lilies, and Rhizopods. The uninitiated would be quite unlikely to recognize the lowest-organized of these, the sponges, as animals.

Among the sponges the glass sponges provide a large number of very striking inhabitants of the depths. The skeleton of the glass sponge differs from that of the bath sponge, which is formed of a pliable horny substance that fits the sponge for its many uses in human households. The skeleton of the glass sponge is a complicated structure of interlocked siliceous spicules or needles, often of a fineness and delicacy suggesting spun glass. The best known is the Watering-can sponge or Venus's Flower-basket (Fig. 39). This lives at great depths in the Pacific, but is found at times off the coast of Japan in dense colonies at depths of 200 to 300 metres. It was a frequent wedding-present in Japan, on account of a peculiar feature regarded as of symbolic interest. In a cavity within this sponge are found almost always a couple of small isopod crustaceans. In their youth these little animals find their way in through the fine pores of the walls of the cavity, and later, when they are fully grown, they are unable to leave it. So they live there in exemplary harmony ever after!

Another most remarkable form is the deep-sea *Monorraphis* ("One-needle") sponge, found in the Indian Ocean off the coast of Africa (Fig. 40); its skeleton consists of a single strong spicule of silicon. It has only been possible to bring up bits of this sponge, but from fragments of the skeletal "needle ", about a third of an inch thick, it has been calculated that the complete sponge may well be at least a couple of yards long. The "needle" extends beyond the body, and probably sticks in the ocean floor.

Many polyps also dig the end of stalk-like formations into the soft mud of the ocean floor; the actual polyp colony grows at the tip of the stalk like a crown. One of these, found east of Japan at 5000 metres below the surface, is the "Imperial Wax-flower hydra" (*Branchiocerianthus imperator*, Fig. 41), reaching a height of nearly 8 feet. Deep-sea species of the sea pen, similarly formed but more delicate, sometimes reach almost the same height, on similar waving stems (Fig. 41). All these polyps belong to the class of sea nettles (Coelenterata), referred to above, and form colonies made up of the many individual polyps. Similar in outward appearance to these tall stemmed polyps are the sea lilies (Fig. 44), tall animals with a wreath of tentacles round a mouth opening in their midst. These

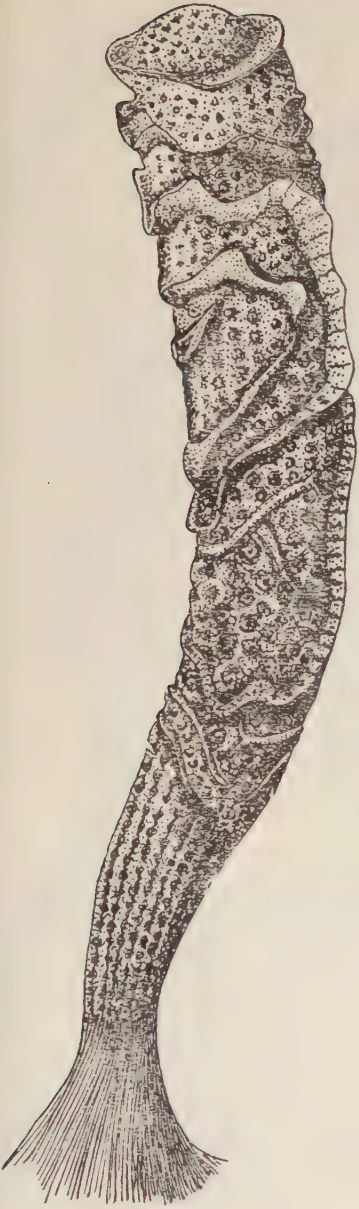


FIG. 39.—Watering-can sponge or "Venus's flower-basket" (*Euplectella aspergillum*). Indian Ocean and Western Pacific, 200 to 1800 metres. Half natural size.

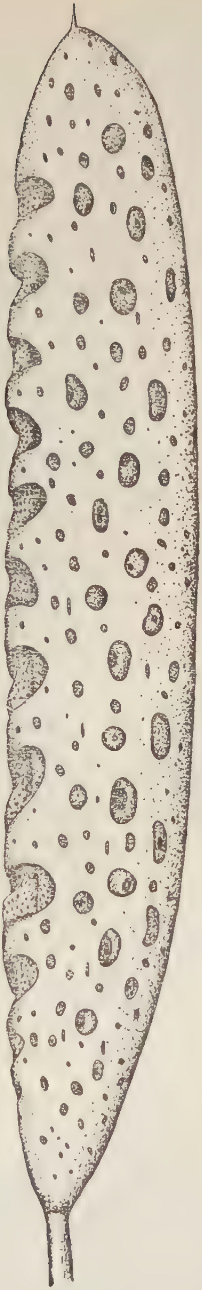


FIG. 40.—Deep-sea sponge (*Monorrhaphis chuni*) Indian Ocean, 1000 metres. One-tenth natural size.

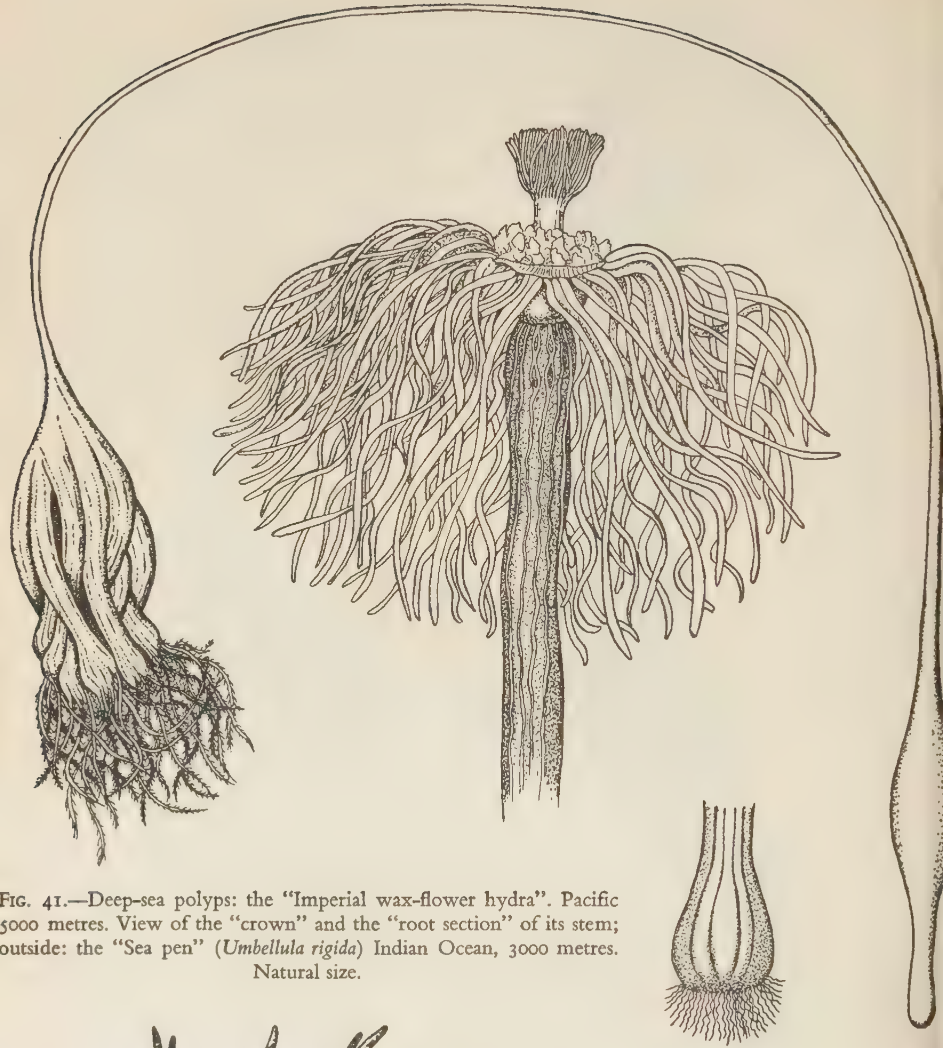


FIG. 41.—Deep-sea polyps: the "Imperial wax-flower hydra". Pacific 5000 metres. View of the "crown" and the "root section" of its stem; outside: the "Sea pen" (*Umbellula rigida*) Indian Ocean, 3000 metres. Natural size.

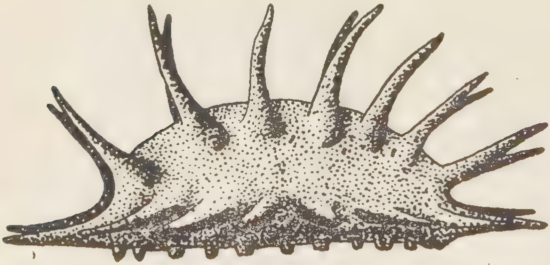
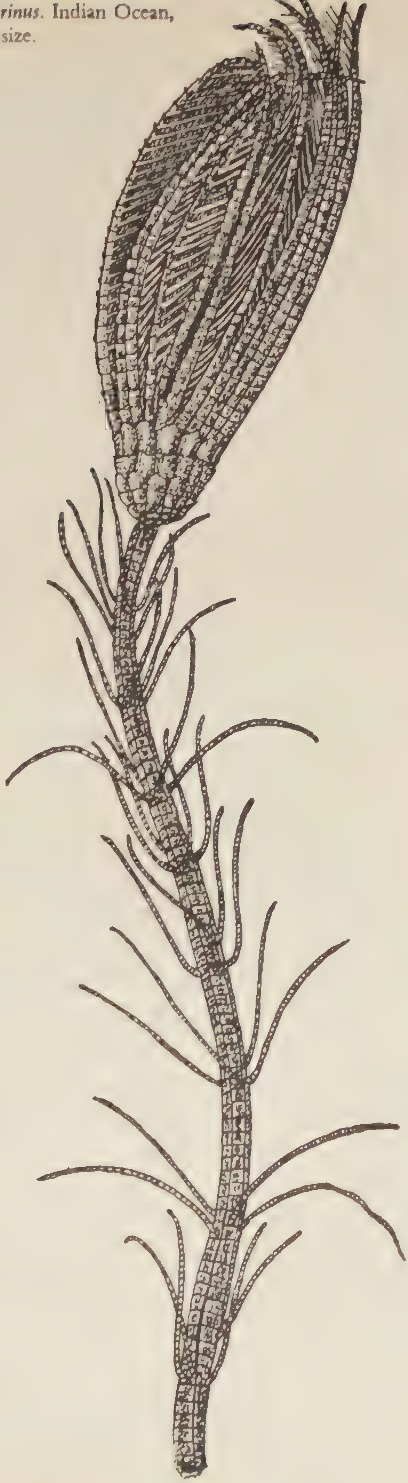
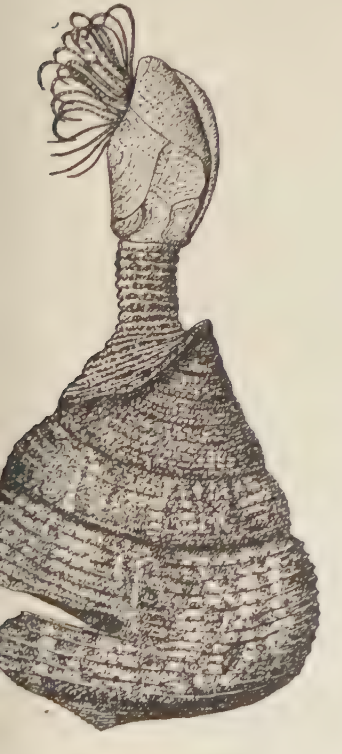


FIG. 42.—A typical deep-sea form of the sea cucumber (*Deima valida*). Pacific, below 2000 metres.

FIG. 44.—Sea lily of the genus *Pentacrinus*. Indian Ocean, 1300 metres. Natural size.



G. 43.—Slit-shelled mollusc of the
nus *Pleurotomaria*, a form of inverte-
ate almost unchanged since remote
es, now confined to the deep sea,
ith a barnacle of the genus *Scalpellum*
it. Western Pacific, down to 3000
metres. Two-thirds natural size.



belong to the class of Echinoderms and so are related to the sea urchins and sea cucumbers and to the starfishes and brittle stars. The resemblance mentioned is purely superficial; the sea lilies are individuals, not colonies, and as Echinoderms they are of much more highly organized internal structure. Like coelenterate colonies, the sea lilies often form great groups, covering the bottom in suitable places almost like forests: with their tall stalks and their tentacles they invite that comparison. The sea lilies or Crinoids especially, with their stiff, chalky skeleton, which only permits slight movements of their limbs, give a bizarre, primeval impression, and in many places their stalks, often several yards long, lie in intertwined masses on the floor of the ocean. They are also very brittle, and so are best suited to the still water of the depths. There they sway gently in the slowly moving current, and they can also make slight independent movements and slowly turn or open and close their feathery "crowns".

Many of the sessile animals of the deep-sea floor, however, cannot simply root themselves, like the foregoing, in the mud, but need a firm substratum, such as stones or mussel shells or other hard lumps, or chance portions of the ocean floor, and they eagerly seize any such opportunity, crowding together on the few spots available. This applies to any species of coral and sea anemone, the mussel-like "arm-footed" Brachiopoda, and also the strange sessile crustaceans belonging to the "tendril-footed" Cirripedia (barnacles). These last are quite unlike normal crustaceans and were formerly regarded as mussels; in that belief no less a figure than Goethe devoted to them a fine inspiring essay. The German maritime folk call them "duck mussels" (*Entenmuschel*), a name preserving an old belief that they could turn into ducks and fly away. More attention is paid today to the practical consideration that species living in shallow water settle on the hulls of seagoing ships and so give trouble. The deep-sea forms of these crustaceans belong to the genus *Scalpellum.*

The "arm-footed" Brachiopoda are a single small family which in past geological periods was widely distributed at times; today it has relatively few species, all marine. It is a strange fact that they have changed hardly at all through hundreds of millions of years. They owe their name to an ancient misconception: like the molluscs, among which they were formerly classed, they have neither arms nor feet. In reality, as is known today, they are allied to certain groups of worms. Of the two shells between which they are enclosed like mussels, one is almost always a good deal larger than the other, and is pierced by the muscular "arm" with which they fix themselves to some supporting substance. They avoid the mud of the abyss; yet the *Valdivia* brought up a specimen from a great depth in the Indian Ocean which had root-like extensions of its "arm", with which it had anchored itself to the shells of minute Radiolaria that formed the ooze at the bottom. (See initial letter I, Chapter III.)

Characteristic of the deepest parts of the oceans, in addition to these sessile animals, are the crawling Echinoderms. Among these the deep-sea representatives of the sea cucumbers (Holothuria, Figs. 42, 128) especially are strikingly formed; for many of the sea cucumbers living in the deep sea diverge remarkably from the general form of sea cucumbers, and especially from the peculiar elongated tubular form of their shallow-water representatives, to which they owe their name.

The remaining groups of the Echinoderms, the starfishes and brittle stars and the sea urchins, have many members living entirely in the deep sea (Fig. 125), but these are not markedly different in appearance from the shallow-water members of these orders. The deep-sea sea urchins of the genus *Pourtalesia* have a quite abnormal bodily form for these animals; for the rest, the largest known sea urchins are deep-sea animals: *Hygrosoma hoplacanthus*, a foot thick, belongs to the family of leathery sea-urchins, which live almost entirely in the deep sea. This species is found in the ocean at 5000 metres down.

We shall often come again upon the fact that the largest members of marine families live in the deep sea. Examples of these among the benthal animals living at very great depths are the giant isopods, *Bathynomus doederleini* and *Bathynomus giganteus*, much the largest members of the Isopoda, an order of crustaceans to which the European wood-louse belongs. These species of *Bathynomus* live in the ocean at a depth of 2000 metres and more. They grow to a length of 6 to 8 inches and have big eyes. Other deep-sea isopods are blind, but often have enormously long legs and feelers, which enable them to move rapidly over the ooze and make up for their blindness by helping them to feel for their prey (Fig. 46). Long slender extremities, sometimes armed with great spikes, which incidentally help to prevent them from sinking into the ooze, are often characteristic of deep-sea crabs. The most notable one is the *Platymaia wyville-thomsoni* (initial letter L, Chapter 2) of the Indian Ocean, named after the scientific director of the *Challenger* Expedition; other crabs will be mentioned later. Hermit crabs, too, are found in the depths, living in carefully chosen empty snail shells, as on the European coasts. Among the deep-sea hermit crabs mention should be made of those on whose borrowed shells colonies of sea anemones settle. The sea anemones absorb the chalk of the snailshell, leaving only its horny substance. This reduces the protection given by the shell, but the cartilaginous substance of the basal plates of the sea anemones compensates for this. The hermit crabs and their sea anemones thus live together in a genuine symbiosis, a partnership that benefits both: the crab has the protection of the sea anemones with their stinging filaments and the firmness their basal plates give to its dwelling; the sea anemones are converted from sessile to freely moving animals and share their host's meals.

An independent group of the marine Arthropoda is formed by the sea-spiders (Pycnogonida or Pantopoda). Most of its species

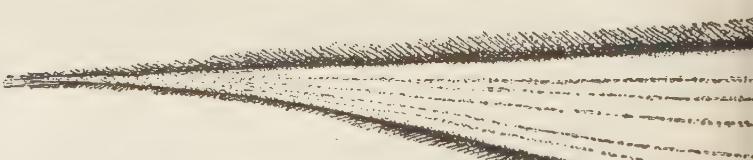
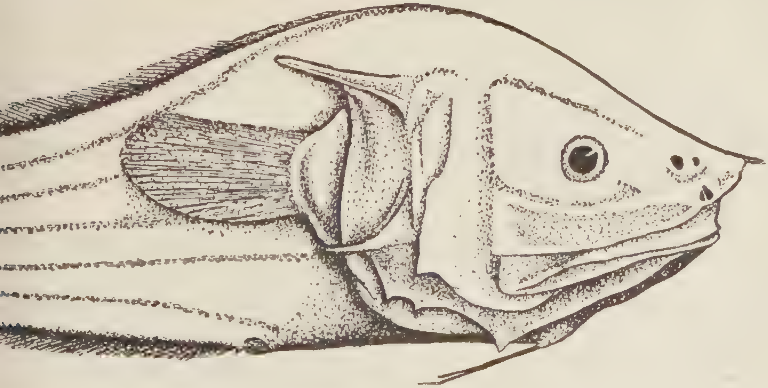


Fig. 45.—The deep-sea benthal fish *Acanthonus armatus*. Western Pacific, 1800 metres. Two-thirds natural size.

live on the floor of the ocean at great depths: of their six or seven pairs of legs the four at the rear are very long and thin, which must be of great assistance to them on the soft mud (Initial letter F, Chapter 6). Their insignificant body is out of all proportion to the tangle of long legs. They have a long, often knobby snout as their most striking feature. Important organs of the Pycnogonida, such as lobes of the stomach and the sexual organs, are placed in the legs owing to the underdeveloped state of the body. These animals fall upon sea anemones and polyp-stems, to suck them dry; the largest species (genus *Colossendeis*) may extend with outstretched legs to 18 inches.

The animals of the deep sea, like those of shallow waters, have three sources of food. They may feed on the organic material sinking from the upper water, or they may gain their means of subsistence from the organic material in the ooze, or they may live as predators, devouring smaller or larger animals. The minute organic remains raining down as detritus are consumed by the sessile animals, with the aid of special adaptations to be described later. For this method of feeding, the importance of the sea, of water itself as the nourishing mother of all life, becomes obvious: the water contains directly assimilable food ready in all places for its inhabitants, brings it to them and leaves them to take it. Only in the water, therefore, are living conditions such as those of the sessile



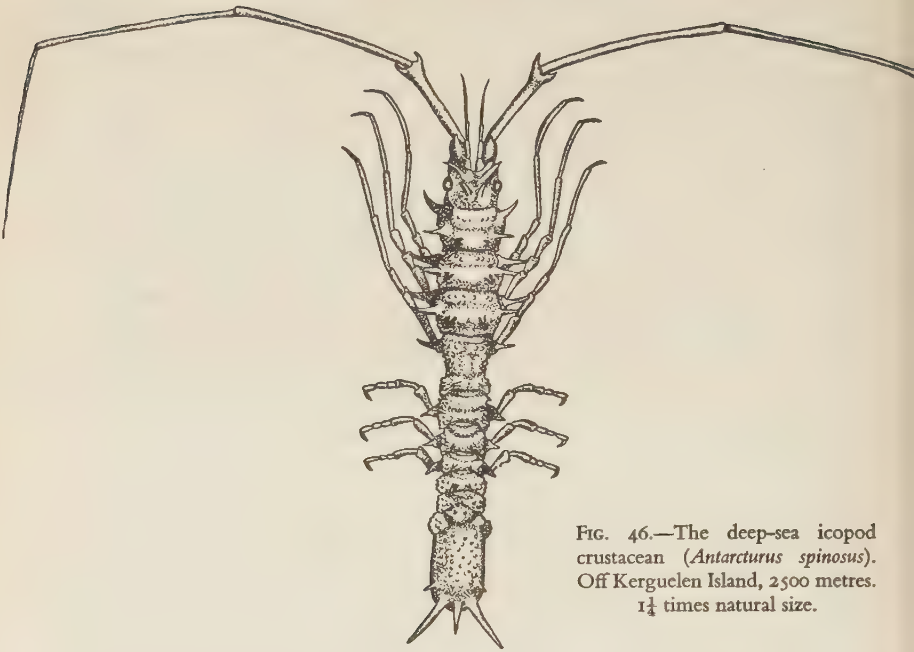


FIG. 46.—The deep-sea icopod crustacean (*Antarcturus spinosus*). Off Kerguelen Island, 2500 metres. 1¼ times natural size.

animals possible; we find them nowhere on dry land; only every animal must actively acquire its food. The ooze-eaters include most of the worms, the sea cucumbers, and many benthal crabs; the predatory animals include starfishes and sea urchins and especially the deep-sea fishes.

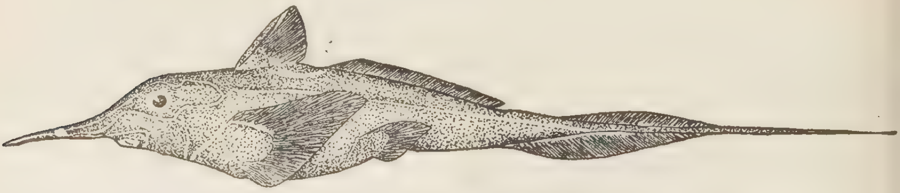


FIG. 47.—The Long-nosed chimaera (*Harriotta raleighana*). North Atlantic, below 1000 metres. One-sixth natural size.

The underslung jaw of many benthal fishes points to special feeding habits. A striking feature of the fishes living at the bottom of the ocean is the lack, almost universal among them, of a developed tail-fin; the end of the body is pointed, bordered only by a narrow fringe of fin. Another striking feature in these entirely lightless depths is the well-developed eye, combined with absence of light organs. It has been surmised, however, in view of the forks and channels on the heads of the macrourid fishes, that they secrete an illuminating substance.

While the deepest regions of the floor of the ocean must be regarded as a sort of desert with relatively few inhabitants, the population of the benthal regions at a rather smaller depth, between 2500 and 3500 metres, is very substantially increased. Forms clearly related to those just mentioned, or identical with them, are found at this depth, and among the fishes the orders and families mentioned are found again, in greater numbers and a greater variety of species. We also find here, around 3000 metres below the surface, other benthal fishes which live habitually at that depth. Among these new species, met with here for the first time, is the remarkable Long-nosed chimaera (*Harriotta raleighana*, Fig. 47), living in the North Atlantic, a fish classed among the small and distinct Selachian group, Chimaerae and benthal eels such as the genus *Histiobranchus* (Fig. 48).

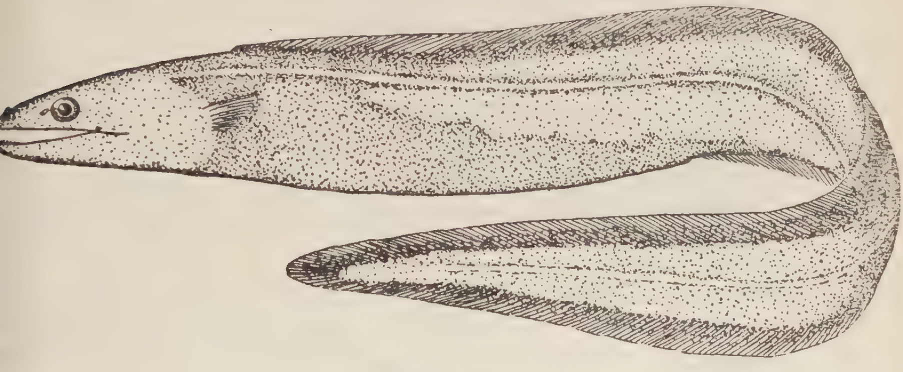


FIG. 48.—The deep-sea eel (*Histiobranchus infernalis*) Pacific, 1800 to 3000 metres. One-fifth natural size.

The invertebrates also are found in much greater numbers in these lesser depths than in the abyss; the species found are either the same as those in the great depths or closely allied to them. We can see the increase in the number of individuals and species of the benthal fauna between 2500 and 3500 metres from a comparison of the dredging hauls of the research ship *Michael Sars* with those from the lowest depths which were given above:

2603 metres, two hours—yield, many glass sponges, hundreds of sea cucumbers, many prawns, 13 benthal fishes (9 *Macrurus*, 1 *Halosaurus*, 1 *Bathysaurus*, 1 *Harriotta*).

2615 to 2865 metres, three to four hours: yield, 2 large and many small sponges, 3 mussels, 5 deep-sea stalked barnacles, 15 hermit crabs, 1 ten-footed crab of the genus *Munidopsis*, 500 sea cucumbers, 31 benthal fishes (17 *Macrurus*, 5 *Halosaurus*, 2 *Benthosaurus*, 2 *Bathysaurus*, 5 benthal eels of the genus *Synaphobranchus*).

3120 metres, five hours: yield, hundreds of sea cucumbers, sea urchins, starfishes, and brittle stars, some crabs, and 20 benthal fishes (genera *Macrurus* and *Histiobranchus*).

Still more profuse is the benthal population found by dredging from the continental slopes at depths between 200 to 400 and 1000 or 1200 metres. In these regions we meet not only with the ooze of the depths but also with a sandy or stony and rocky floor, such as is the exclusive habitat of many benthal animals. We find here

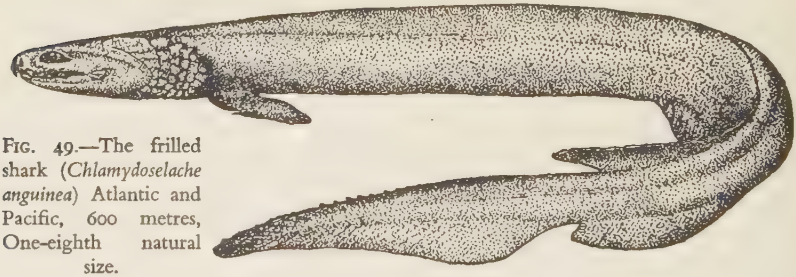


FIG. 49.—The frilled shark (*Chlamydoselache anguinea*) Atlantic and Pacific, 600 metres, One-eighth natural size.

in the first place many fishes of the families met with already, but the majority are not found in the abyss. In addition, however, to these there are benthal fishes of many other families which are rarely found below or away from the continental slopes. One of these is the Frilled shark (*Chlamydoselache anguinea*), whose discovery by Doederlein and Garman aroused great interest because this shark is very closely allied to forms which have been extinct for many millions of years. It lives some hundreds of metres below the surface, off the coasts of East Africa and western Europe.

Among the dwellers on stony or rocky bottoms are the very curious bat fishes (*Oncodidae*, Figs. 50, 52). These animals are so well fitted for benthal life with their spikes and humps that at first sight they look more like toads and frogs than fishes. This impression is created not only by their form but especially by their wide mouth, with which they snap up all the small animals that incautiously approach them, and their pectoral fins, developed into muscular propellers, and placed far to the rear, near the root of the tail. The pelvic fins, too, serve for propulsion along the bottom of the ocean.

The sea robins (genus *Peristedion*, Fig. 51) live at considerable depths on the continental slopes; they have pectoral fins with appendages for moving over the floor of the ocean; these are used like fingers or little hooked legs. The sea robins share this peculiarity with all their closer allies; one of these, the gurnard, is a typical and familiar benthal denizen of the shallow water off the continental coasts of the North Sea.

The "Long-beaked bather" (genus *Halimochirurgus*, Fig. 53), living on the floor of the Indian Ocean off the coasts, belongs to the triacanthids, a family to which many of the curiously formed coral fishes of the order of Plectognathi ("joined-jaws") belong; its great eye and its delicate tissues indicate that it is an inhabitant of the depths. Its small superior mouth, set just behind the tip of the long snout, only permits it to eat very small animals, which it sucks down, so to speak, by means of a substantial pressure in its long snout when the mouth is opened.

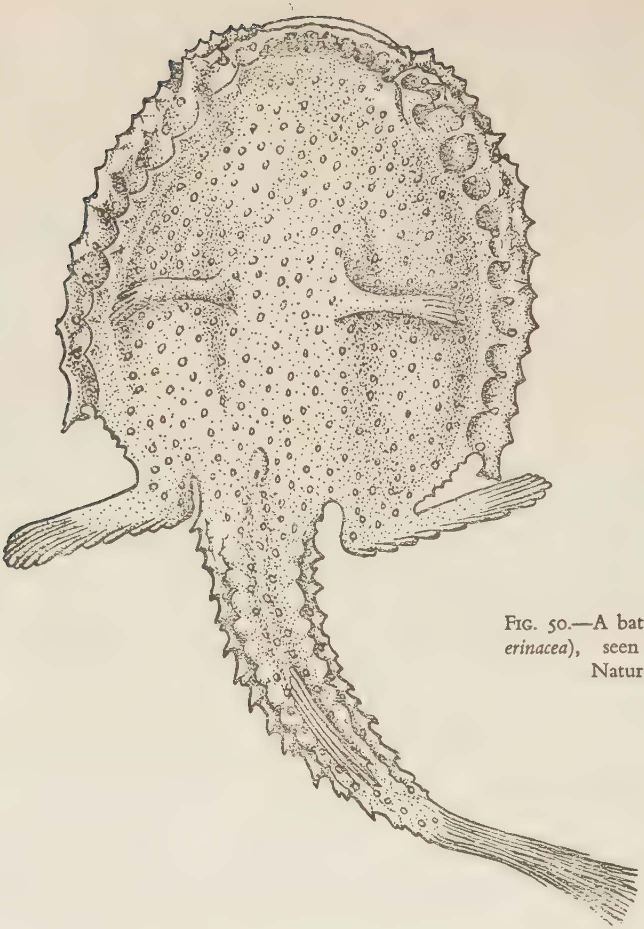


Fig. 50.—A bat fish (*Malthopsis erinacea*), seen from below. Natural size.

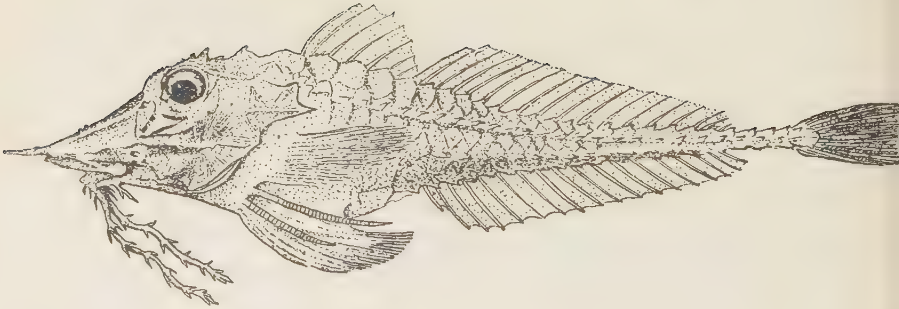
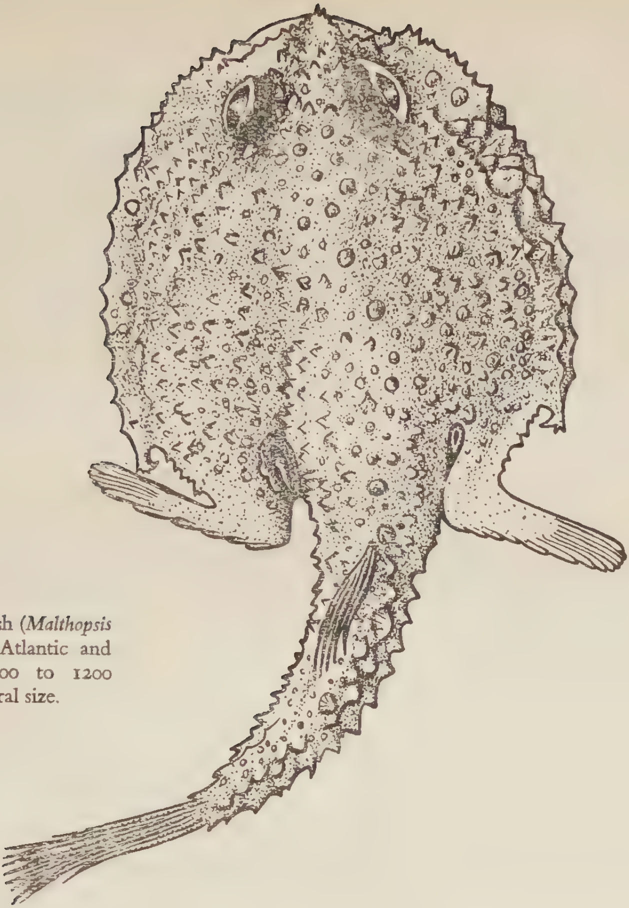
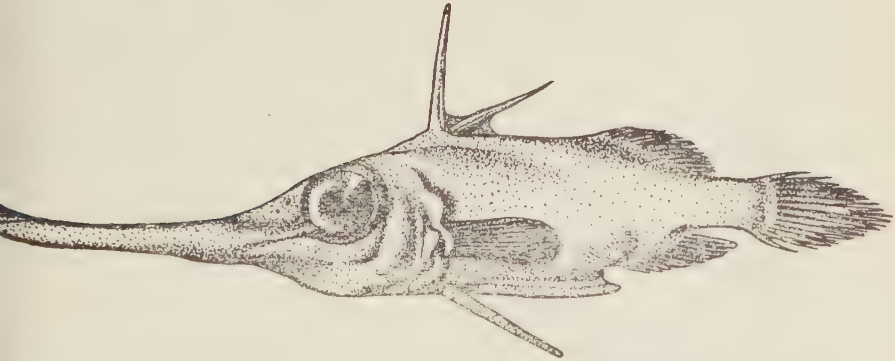


Fig. 51.—The sea robin (*Peristedion miniatum*). Atlantic, about 300 metres. One-fifth natural size.



G. 52.—The bat fish (*Malthopsis*
nacea). Western Atlantic and
stern Pacific, 800 to 1200
metres. Natural size.



IG. 53.—The "Long-beaked Sea-bather" (*Halimochirurgus centriscoides*). East African coastal waters, 300 metres. Natural size.

In addition to these strange creatures there are many harmless-looking members of the cod-fish family (genera *Bathygadus*, *Mora*, *Antimora*, *Lepidion*, and others) or the ophidoid fishes (genera *Ophidium*, *Leptophidium*, and others) which are typical of the benthal population of the continental slopes at depths around 1000 metres. Deep-sea soles also live here (Fig. 55). There are also many invertebrate animals living on the floor of the ocean that do not reach the lowest regions of the abyss but live on the continental slopes down to a depth of 1000 metres. They show no marked difference from allied dwellers in the deepest depths, and have much the same feeding habits. Notable among them is the orange-coloured giant crab (*Kaempfferia kaempfferi*) of the western Pacific; the larger females with their long thin legs extend to six feet. They are much the biggest crabs known, and are one more instance of the biggest members of a group of invertebrates being found in the depths. In the same region, again in the Indian Ocean, lives the strange octopod of the genus *Opisthoteuthis* (Fig. 54). These octopods, with their flattened body, their arms often bound together with only a short free end, and their great eyes, protruding like those of frogs, which may be a third of the size of the body, are quite unlike most of the octopus group. Their form is certainly well adapted for life actually at the bottom of the sea; fishes, too, as we saw in the case of the bat fish, diverge greatly from the norm of their type for a benthal existence.

The squids of the genus *Rossia*, again in the Indian Ocean, live at the bottom in coastal waters (Fig. 57). They belong to the family of the ten-armed squids, most of which are swimming animals. Its life at the bottom has changed the appearance of the *Rossia* less noticeably from that of the rest of its family than is the case with the *Opisthoteuthis*—partly because it does not lie flat on a firm substratum like the *Opisthoteuthis*, but lives on sand or ooze, in which it wallows with the aid of its broad side-fins.

In *Opisthoteuthis* we have a representative of the eight-armed group of cephalopods almost all of which live at the bottom of the

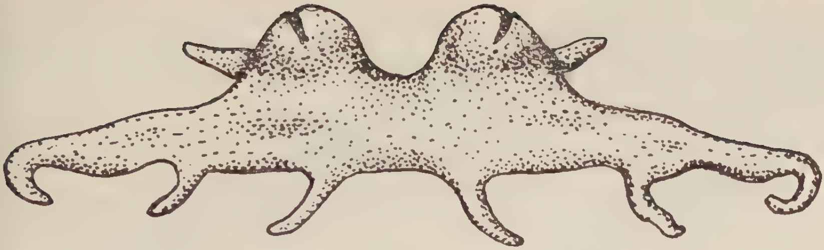
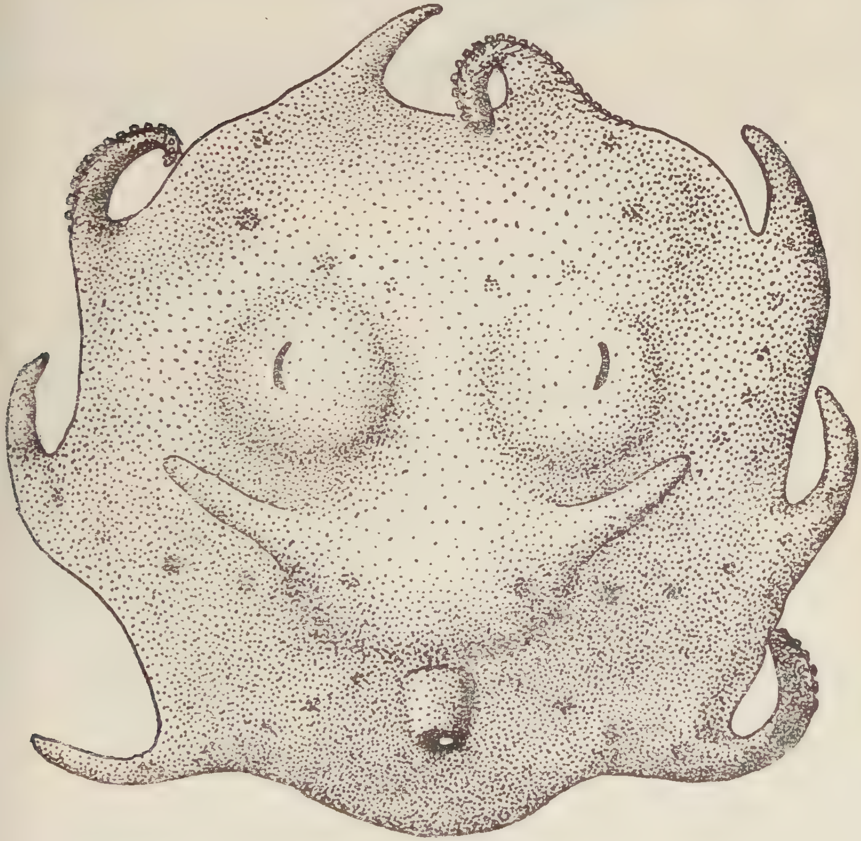


Fig. 54.—The deep-sea benthal octopus (*Opisthoteuthis depressa*). Indian Ocean and Pacific, 400 metres. View from side and from above. One-third natural size.



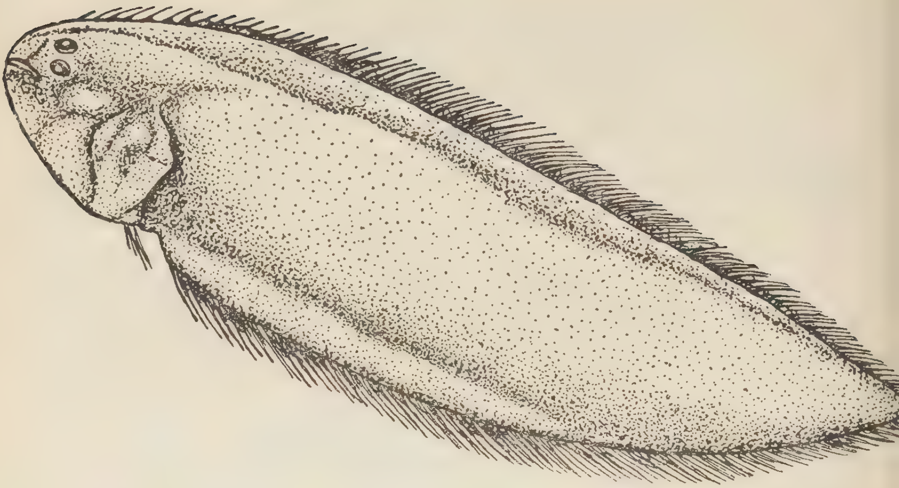


FIG. 55.—A deep-sea sole (*Aphoristia wood-masoni*). Indian Ocean, 800 metres. Natural size.

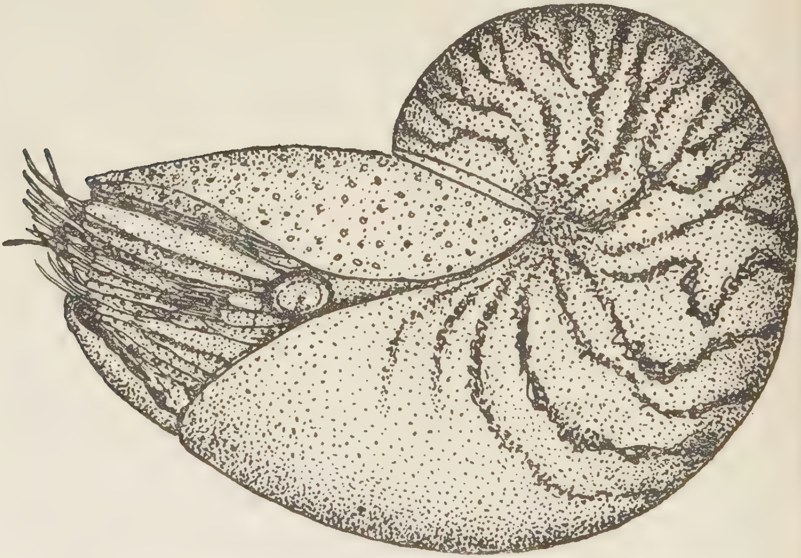


FIG. 56.—The pearly Nautilus. Indian Ocean and Pacific, 400 metres.
One-quarter natural size.

ocean; *Rossia* is a member of the ten-armed group, most of which, unlike *Rossia*, are pelagic animals.

Outside these two great groups of the cephalopods with two branchiae stands the pearly Nautilus (Fig. 56), the last living representative of cephalopods with four branchiae. Like its primeval relatives, long extinct, it possesses a great spiral (though flat) shell with many chambers. This shell resembles those of countless fossil ammonites, some of which are as big as a cart-wheel. These are shells of extinct four-gilled cephalopods, from which the Nautilus is not directly descended. Of the many successive chambers in its shell the animal lives only in the foremost one; the rest are filled with gas and have a similar function to the swim-bladders of fishes, that of a hydrostatic apparatus. The animals are able to vary the gas content and pressure in the many chambers, and so to alter their specific gravity, enabling them to rise or sink in the water at will. As a rule, however, they seem to live on the sea floor, at a depth of some hundreds of metres; they are found in the eastern Indian Ocean and the western Pacific. The shell of the dead Nautilus rises to the surface owing to its gas content, and in some places the shells are washed up in heaps. They have been valued in all ages, and were sought after in Europe in the seventeenth and eighteenth centuries, for their beauty of form and also for the mother-of-pearl surface revealed by polishing.

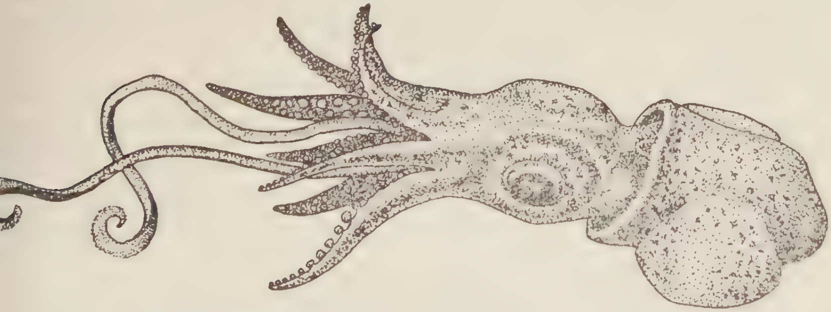


FIG. 57.—The benthal squid (*Rossia mastigophora*) East African coastal waters, 630 metres. Two-thirds natural size.

CHAPTER IX

THE PELAGIC FAUNA OF THE DEEP SEA

The plankton – Its diminution as the depth increases – Medusae, worms, and giant ostracods – The poet Chamisso and the generations of the salps – Prawns – The "wonder lamp" – Giant octopods – The "little post-horn" – Fishes of the greatest depths – Stomiatoids and hatchet fishes – Gulpers and snipe eels – The giant-swallowers and their enormous stomachs – Devils and goblins of the deep sea; their strange forced marriage

Different entirely from those of the benthal population of the depths are the composition and the habits of the bathypelagic animals, that is to say those which do not live on the floor of the ocean but in the dusk or darkness of the deep water.

The small creatures of the plankton are found in the deep waters, even in the greatest depths of the oceans. In those regions, where little light penetrates, or none at all, the deep-sea plankton contains no plant organisms, only animal ones, for the reasons already given; the only exceptions are the so-called "olive-green cells". These are unicellular algae; they are found in relatively small quantities, ekeing out an existence in some unknown way.

The quantities of minute plankton animals found in the vast spaces of the ocean depths are incomparably smaller than those found near the surface of the ocean. At depths of 50 metres or less, between 3000 and 100,000 plankton creatures have been counted in a litre of water; at depths over 2000 metres the figure varies between 100 and 10 to the litre (Fig. 5).

That these figures are primarily dependent on the varying density of the plankton at the surface, was shown by our diagram of the frequency of plankton organisms at about 2000 metres below the surface in the South Atlantic; it was shown above how the life in the deep sea is dependent on the population of living creatures nearer the surface. The extraordinary falling-off in the numbers of the plankton animals in the depths exemplifies the general paucity of living beings there compared with the numbers near the surface.

TABLE 5

Average numbers of plankton creatures at increasing depths in the Atlantic, off Ascension

Depth in metres	*Living cells in a litre of water*
0	10,147
50	9,443
100	2,749
200	726
400	261
700	114
1000	87
2000	57
3000	18
4000	17
5000	15

In net hauls from deep water, in any case, the small animals of the plankton, especially the copepods, outnumber the other animals and the fishes.

The number of species in the plankton does not fall as strikingly as its number of individuals. Two or three families of the unicellular Radiolaria live entirely or almost entirely in the depths, among them the characteristic forms of the genus *Protocystis* (family Challengeriidae, Fig. 58) and the genus *Tuscarettia* (family Tuscaroridae, Fig. 59); many individuals of the Tuscarettiae, distinguished by

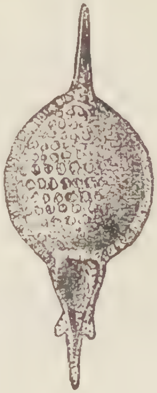


FIG. 58.—The radiolarian (*Protocystis swirei*) found from the surface of the Polar seas down to 5000 metres. Magnified 200 times.

curious long extensions of their shells, live usually in colonies of various sizes, protected by siliceous latticed globes. Some groups of families, too, of planktonic Coelenterata, the Medusae, the Portuguese men-o'-war, and the sea gooseberries, are associated entirely, or almost entirely, with the deep sea, among them many species of striking beauty of colouring, delicate red, violet, and brown, or black (Fig. 60). Among the worms in the deep-sea plankton are the rudimentarily organized Nemertini with very distinctive forms.

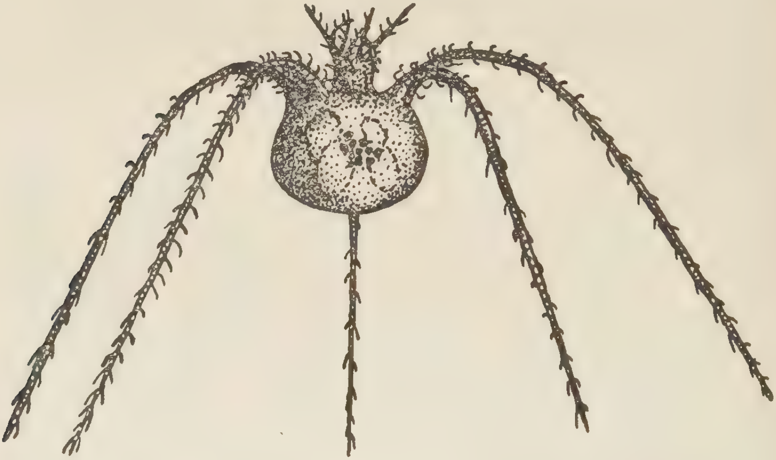


Fig. 59.—*Tuscarettia globosa,* a deep-sea radiolarian. 2000 metres. Magnified 200 times.

An important further element in the deep-sea plankton is formed by the minute crustaceans, such as the copepods (Fig. 5, B, C, D) and the ostracods, entirely enclosed in their double shell; of these much the largest species, the orange-red *Gigantocypris agassizi* (Fig. 61), named after the great Swiss-American scientist Alexander Agassiz, is a giant among the little Ostracoda, reaching the size of a cherry; it lives entirely in the deep sea.

Of the higher forms, the "shelled crustaceans", species of the Schizopoda (Fig. 5, A) belong mainly to the deep-sea plankton, and are found in swarms at considerable depths. Curiously enough, the order of echimoderms, otherwise entirely a benthal family, at all events as adults, have one species belonging to the pelagic fauna of the deep sea: this is the swimming sea cucumber of the great oceans (genus *Pelagothuria*, Fig. 5, H); it has twelve tentacles, about 5 inches long, most delicately webbed.

Closely related to the echinoderms, though superficially quite unlike them, are the arrow worms (Chaetognatha), whose few members (genus *Sagitta* and others, Fig. 5, G) are frequent and characteristic elements of the plankton, both in the deep sea and on the surface. With the Tunicata we come to the class of chordate animals, and so, as shown above, to primitive predecessors of the vertebrates, though that relationship is not credited to the Tunicata. To them belong the gelatinous, transparent, tub-shaped salps of the surface and deep-sea plankton, creatures of the size of a man's fist, whose strange interchange of generations the German poet Adalbert von Chamisso, of French origin, was the first to describe; he was an enthusiastic naturalist, and his description of his voyage round the world (1818 to 1821) is one of the jewels of German literature.

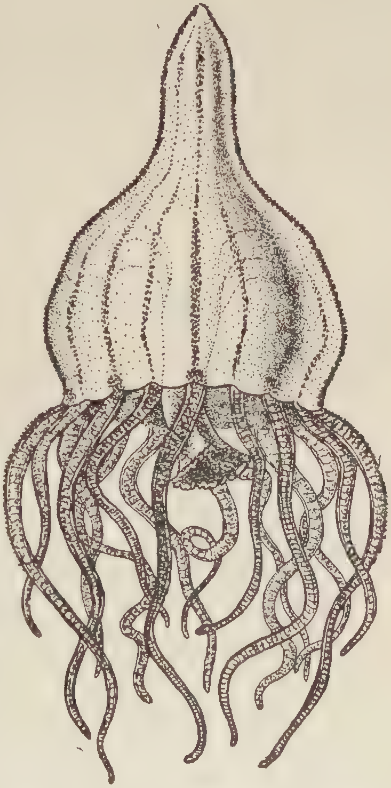


FIG. 60.—The deep-sea jellyfish (*Tesserantha connectens*) Eastern Pacific, 2000 metres. Six times natural size.

Finally, among the primitive Chordata are the lancelet fishes; they are similar in appearance and in bodily functions to the lower-organized fishes; their most famous representative, thanks to the close study given to it, is *Branchiostoma lanceolatum*, a little lancelet fish about 3 inches long living in the sand of quiet shallow bays, especially in the Mediterranean. In the deep sea live rather smaller members of the genus *Amphioxides* as pelagic creatures, apparently in the manner of small plankton animals.

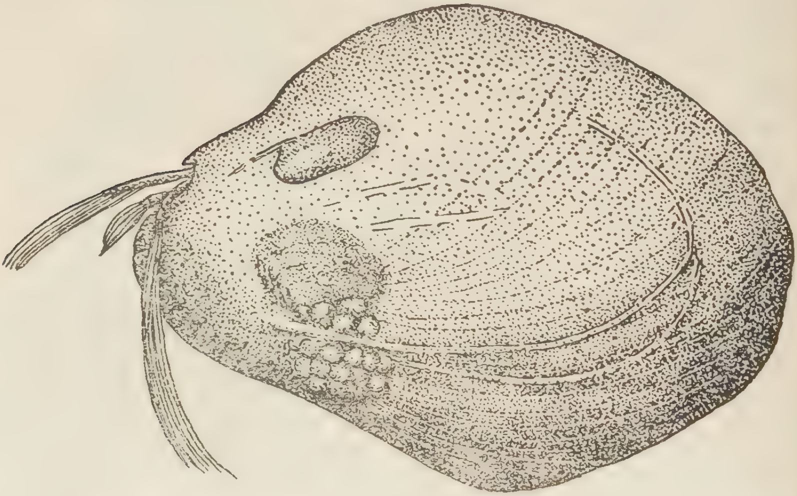


FIG. 61.—The giant ostracod crustacean (*Gigantocypris agassizi*). Deep sea, Atlantic and Indian Ocean. 5 times natural size.

Among the deep-sea creatures that do not drift at the mercy of the currents like the plankton animals, but are strong independent swimmers, we find especially the group of more highly organized swimming crustaceans (*Macrura natantia*), belonging to the phylum or sub-kingdom of Arthropoda; the cephalopods (molluscs), and the fishes (vertebrates). The distinction, however, between the plankton animals and the freely swimming is not always entirely definite; many of the deep-sea cephalopods to be named shortly live perhaps more in the manner of the plankton animals than of those actively swimming. Moreover, the distinction applies here only to the adult animals; the larvae and the young of all crustaceans and molluscs and of many fishes, and also of the benthal echinoderms and sessile animals, belong to the plankton; often the larvae and the young animals are very different in appearance from the adults. We shall return again to these points, which have already been mentioned in earlier pages.

The swimming crustaceans or prawns of the deep sea differ from their allies of the shallow seas and the upper waters in being almost always of a luminous red colour; there are no other striking differences. Sometimes, however, they are blind; other species have

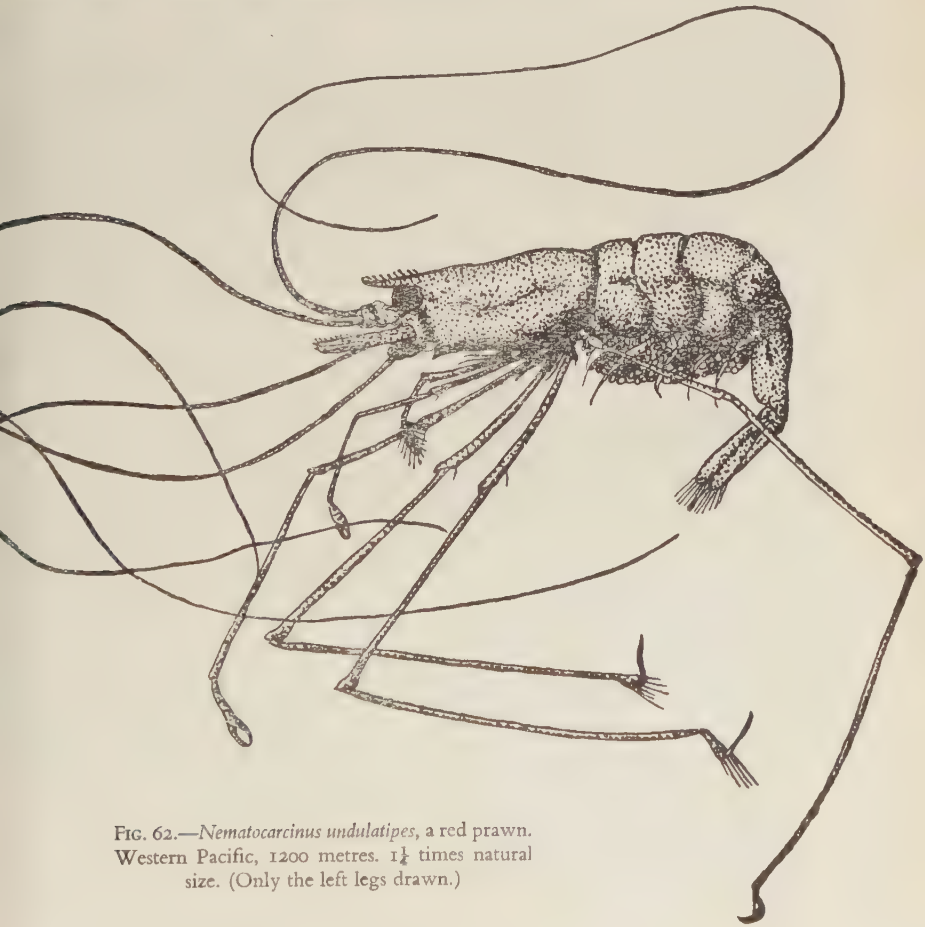


Fig. 62.—*Nematocarcinus undulatipes*, a red prawn. Western Pacific, 1200 metres. 1½ times natural size. (Only the left legs drawn.)

greatly enlarged eyes, and often they have much longer feelers and legs, which probably serve for floating as well as for feeling (genera *Notostomus*, *Nematocarcinus*, *Aristaeopsis*, and others, Fig. 62). Some deep-sea prawns have a capacity of illumination, sometimes connected with special light organs, or the capacity observed by Dr Beebe, as mentioned in Chapter 3, of ejecting into the water substances that light up at once and surround them protectively like a cloud of fire.

The cephalopods are represented among the bathypelagic animals, those swimming in the deep sea, by many species, often of remarkable form. Especially the group of ten-armed cephalopods, the Decapoda, is represented in the bathypelagic (deep-sea) region. These are all beasts of prey, but many of them, owing to their small size, live only on the minute plankton animals and the smallest fishes, which they seize with their tentacles. The tentacles usually have suckers and also hooks, to hold the prey, which is then put into their mouth. Larger animals are poisoned by bites from their strong horny jaws, which resemble parrots' beaks. As invertebrates the cephalopods have no actual skeleton, though many of them have a vestigial shell, inherited from their ancestors, a horny or chalky cuttlebone lying loosely under the skin of their back. A true many-chambered spiral shell like a snail's, but flat, is possessed only by the benthal Nautilus, already mentioned (*Nautilus pompilius*, Fig. 56), among the forms still extant; and the "little post-horn" (*Spirula spirula*, Fig. 66); in this animal too the shell is vestigial, and quite buried in the animal's body; it is not even at the back as in the Nautilus and the fossil ammonites, but rolled in toward the underside.

Usually two of the arms of the Decapoda are greatly extended and serve as tentacles; sometimes the other eight arms are very short; in rare cases the tentacles are absent. In the males one arm, called the hectocotylus, is converted into a marital organ; with it the sperm, rolled together into a characteristic packet known as the spermatophore, are transferred to the female. The males of some species—it is not clear whether deep-sea ones are included—save

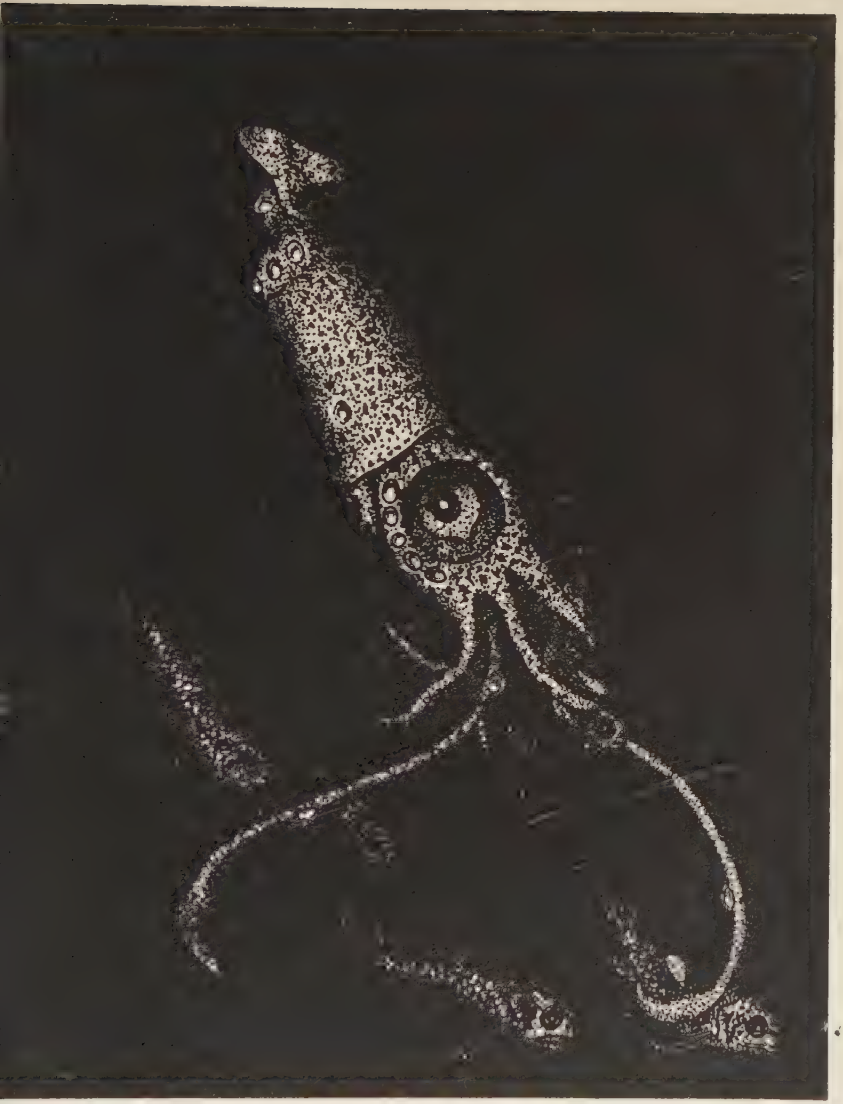


FIG. 63.—The "wonder lamp" (*Lycoteutis diadema*), a deep-sea squid of the South Atlantic, hunting fishes of the genus *Melamphaes*. 1200 metres. Natural size.

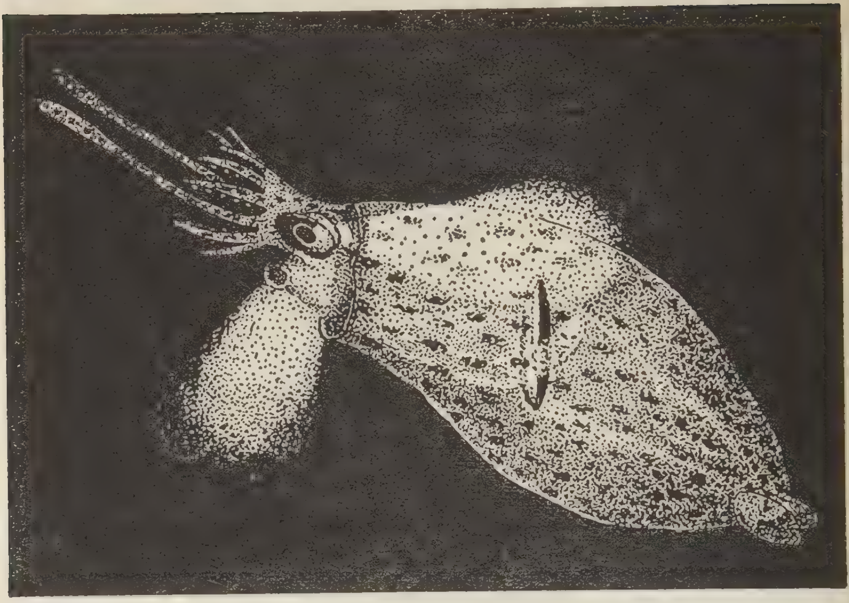


FIG. 64.—The deep-sea squid (*Desmoteuthis pellucida*) with strong lights behind and below the eyes. South Atlantic, 1000 metres. Natural size.

themselves the trouble of looking for a wife by shedding the hectocotylus arm with its sperm packet; the arm then goes on an independent search for appropriate females—one of the strangest marital procedures known in the animal world.

Forms with light organs are frequent among the ten-armed cephalopods of the bathypelagic region. Some are furnished with numbers of small pearl-shaped lights in rows; others have only one large globular light, which they wave in front of them, at the end of each tentacle. Others send out almost magical many-coloured lights, which proceed from light organs arranged round the eyes and on the under side of the body. The most famous of these is the splendid "wonder lamp" (Fig. 63), because its discoverer, Professor Chun, director of the *Valdivia* Expedition, was able to observe a living specimen. Without its arms it is about 3 inches long; it lives in the South Atlantic. It has the great eyes, and the fins at the end of the body, which are characteristic of almost the whole group. Of its twenty-four light organs two are on each of the two tentacles, five on the lower edge of each eye, and the remaining ten arranged symmetrically on the under side of the body.

These last lights are placed under the loose tunic which all cephalopods have as a so-called mantle; the tunic of the "wonder lamp" is transparent, as are those of most deep-sea squids.

"Of all the wonderful colouring the deep-sea animals showed, nothing is remotely comparable with the colours of these light organs. One could imagine that the body was crowned with a diadem of precious stones of many colours: the middle organ beside the eye gave an ultramarine light, and the two on either side of it a mother-of-pearl glow; the front organs on the belly shone ruby red, the back ones snow-white or mother-of-pearl, except the middle one, which gave a sky-blue light. It was a marvel!" So Professor Chun described the "wonder lamp" brought up by the *Valdivia*, alive and still glowing.

The deep-sea Decapoda, generally of the family of the Cranchiidae, have the larger lights only on the outer side of the eyes; we show one, *Desmoteuthis pellucida*, from the depths of the South Atlantic, in Fig. 64. And while the squids in the sunlit regions of the oceans have in their ink-sac an effective means of protection—they eject from it clouds of dark pigment as concealment—we find in some of the deep-sea squids to which, in the regions of eternal night, such a device would be of no service, the capacity to send out from certain glands a luminous secretion such as was mentioned above in the case of some of the deep-sea prawns: by means of it these squids cloak themselves effectively with a cloud of light, behind which they try to evade their enemies.

A striking feature in many of the pelagic cephalopods is the very delicate webbing which unites their arms, forming a sort of umbrella (Figs. 67, 100). The two tentacles of the ten-armed squid are not included in this webbing. Another peculiarity of the deep-sea swimming cephalopods is their translucent, gelatinous body, often very frail, in which their internal organs can be vaguely seen

(Fig. 64); especially the liver, which often, curiously enough, shines through in bright colours. These colours are the end products of metabolism, in which, of course, the liver plays an important part. These colours are not secreted by the liver but deposited on its surface. We find these peculiarities principally in the Cranchiidae, almost all of which belong to the bathypelagic fauna. Many of them have remarkably formed eyes, among them the species belonging to the genera *Bathothauma* and *Sandalops* (Figs. 65, 104), in the South Atlantic, which have light organs just beside the eyes.

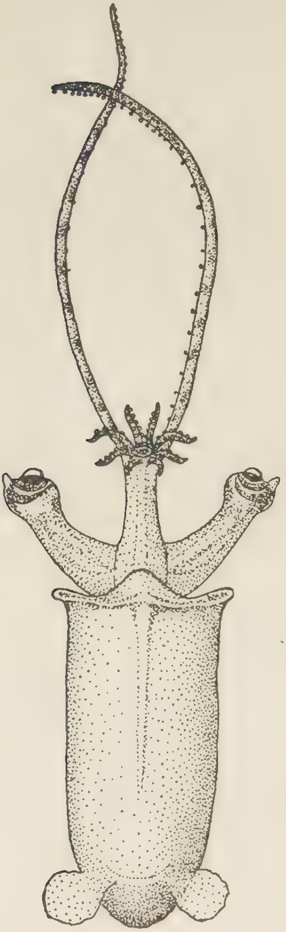
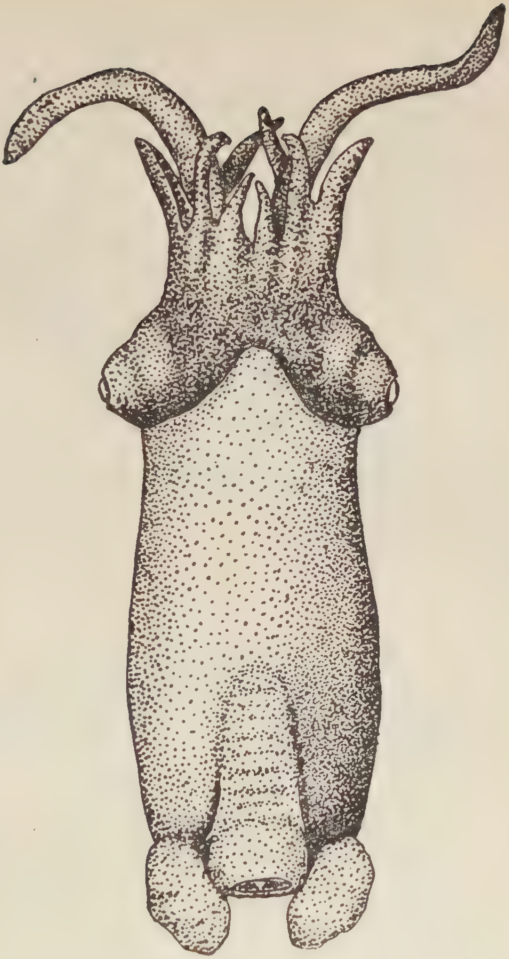


FIG. 65.—The deep-sea squid (*Bathothauma lyromma*) Atlantic, 3000 metres. Two-thirds natural size.

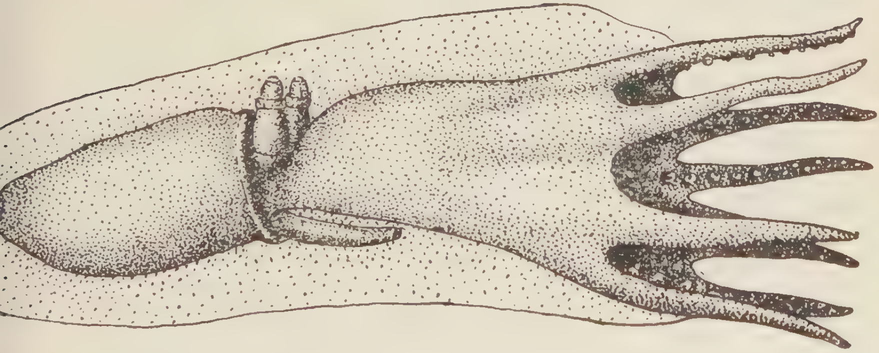
The same bathypelagic life is probably led by the rarely observed giant squid of the family of Architeuthidae. They do not attain the colossal size attributed in old seamen's yarns to the giant octopods, which were said to take four-masted ships in their arms and drag them into the depths, or to be mistaken for islands when floating on the surface; but an Architeuthid nearly 60 feet long was found on the east coast of Newfoundland. Squids and octopods are rarely as much as a yard long, so that this was relatively a giant.

A rather unusual type of ten-armed deep-sea squid is the "Little post-horn" (Fig. 66), whose strange inner shell was mentioned above. This shell again is many-chambered; the first chamber is filled with the animal's organs, the rest with gas, forming here again a hydrostatic mechanism.



66.—The "Little Post-horn" *irula spirula*). Next to it, its shell, ied within its body. All oceans, 300 800 metres. Double natural size.

67.—The pelagic octopus (*Amphi-s pelagicus*) with telescopic eyes nting upwards and a most delicate tinous covering over its body. an Ocean and Pacific, 1800 metres. Nearly double natural size.



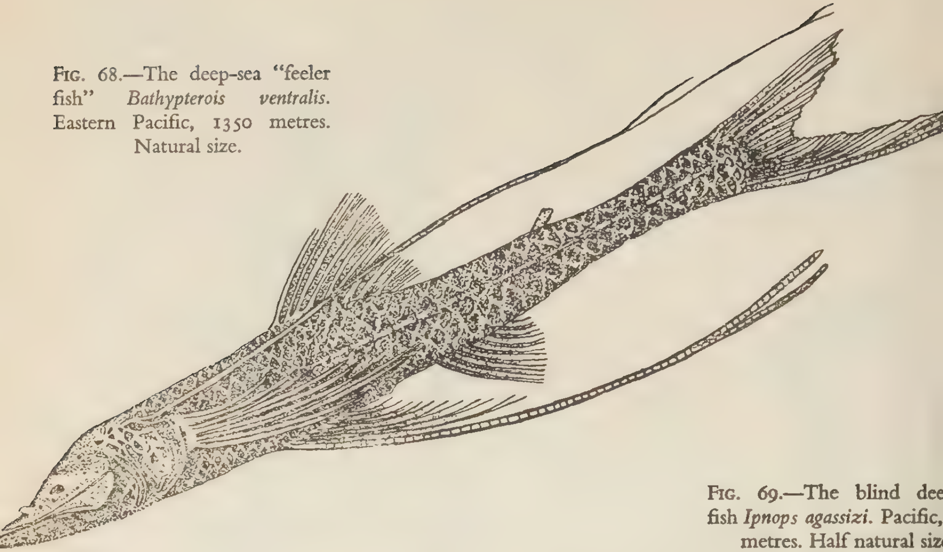


FIG. 68.—The deep-sea "feeler fish" *Bathypterois ventralis*. Eastern Pacific, 1350 metres. Natural size.

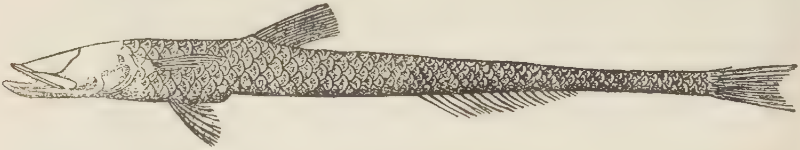
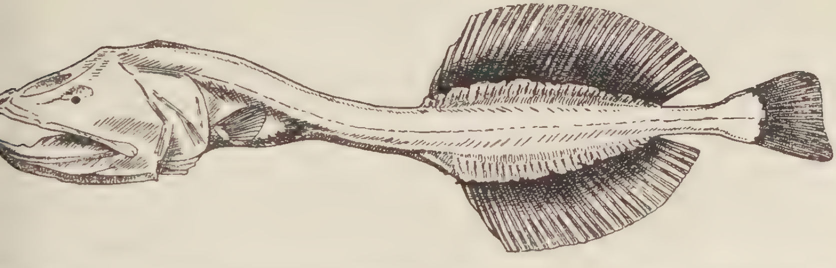


FIG. 69.—The blind dee
fish *Ipnops agassizi*. Pacific,
metres. Half natural siz

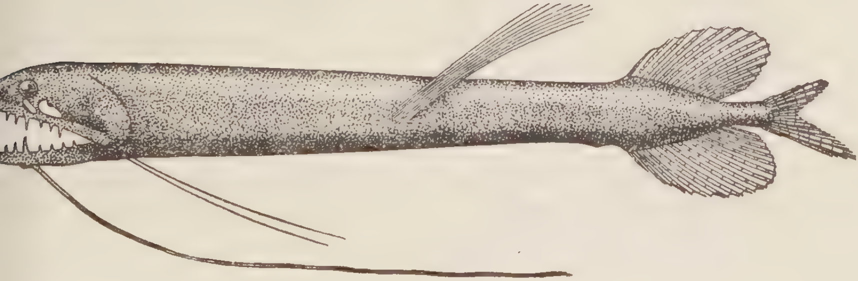
Of the other great group of cephalopods, the octopods, few bathypelagic members are known, but they include such remarkable species as *Amphitretus pelagicus* (Fig. 67) of the Indian Ocean and the Pacific, and *Cirrothauma murrayi* (Fig. 100), from the depths of the Arctic. Both have webbed arms and very fragile translucent bodies, and that of *Amphitretus* is surrounded by a still more easily injured and quite transparent covering, even over the eyes. *Cirrothauma* is the only cephalopod known to be completely blind; *Amphitretus* has two "telescopic" eyes, enlarged in a special way and pointing upwards. The suckers on the *Cirrothauma's* arms are modified in a peculiar way and cannot possibly perform their original function; it has been conjectured that they have become light organs. The strangeness of such a change of function would be increased by the fact that a completely blind animal was producing light which it would never see. We shall find this very thing, however, occasionally in other deep-sea animals.

Among the deep-sea fishes not actually living on the floor of the ocean there is an extraordinary diversity of features and forms, many of them very strange. To begin with, there is a group of fishes, most of them closely related to each other, of the order of the Iniomi; they are allied to the European pike. They clearly live near the bottom in the greatest depths. Many of them are blind, or have small eyes of little real service; some of them have long filaments radiating from the fins on back, belly, or tail, which no doubt serve as feelers to compensate for the lost or deteriorated sight. These features are found especially in species living near the bottom at the greatest depths, belonging to the genera *Bathypterois* (Fig. 68) and *Bathysaurus;* a *Bathypterois* was once brought up alive and observed for a short time, and it is stated that it had filaments as



IG. 70.—*Cetomimus regani*, a fish with atrophied eyes that can no longer see. Atlantic, about 3000 metres. Four-fifths natural size.

FIG. 71.—The deep-sea stomiatoid (*Bathophilus melas*). Western Atlantic, 600 metres. Three times natural size.



long as its body on its pectoral fins, and would stretch them in front of it like feelers. Allied species, blind or almost blind, living at these great depths, such as those of the genera *Ipnops* (Fig. 69), *Bathymicrops*, or *Cetomimus* (Fig. 70), have no such filaments. We know nothing of the food or the habits of these fishes; their mouth has only very small teeth and is deeply cleft. These fishes have no light organs; only the little *Ipnops* has a big double organ in its flattened head under the translucent skull-bones, which has been pronounced a light organ. Whether the many deep-sea fishes of the eelpout family (mainly Brotulidae and Ophidiidae), most of which have very small eyes but are not completely blind, are at least in part bathypelagic or are all benthal, has not yet been determined; some of them have been mentioned above as benthal fishes. The Liparididae, allied to those mentioned, are as a rule benthal; they have a sucker formed by the belly-fins, for adhesion to stones and the like on the ocean floor; but in the Liparididae this sucker is more or less vestigial, while some rays separated from the pectoral fins and moved toward the belly increase in length in compensation. Both features may indicate that these fishes have exchanged their benthal existence for a bathypelagic one, to which they clearly belong in view of the circumstances in which they were caught; they may have been driven to this by a lack of stones in ooze at the bottom. At the very great depths in which they have usually been found, the lengthened pectoral-fin rays probably serve them also as feelers; but almost all of them have good eyes, sometimes enlarged—but no light organs.

A typical representative of these deep-sea Liparididae is *Careproctus longifilis* (Fig. 72), which was brought up from 3500 metres below the surface off the coast of Ecuador; and similarly marked by atrophy of the sucker on the belly and lengthening of the first filaments on the pectoral fins is *Rhodichthys reginae*, which lives at an equal or greater depth in the North Atlantic.

Among the fishes living in the greatest depths and probably near the bottom should perhaps be included the gulpers (Saccopharyngidae) and some deep-sea eels, but these are also found at lesser depths, so that they will be referred to later.

Large groups of deep-sea fishes, including whole families from various orders of fishes, do not live at such depths as the foregoing. To these others belong almost all the genera, groups of genera, and amilies with a faculty of illumination, often intensive, and in many ases with special features in the formation of their eyes and a apacious predatoriness; they prefer the medium depths, with an upper limit between 500 and 800 metres and a lower limit between 00 and 1800. It was mainly these that Dr Beebe found as the most triking and most frequently observed of the bathypelagic fish-auna. First there is the whole group of families of the Stoniatoidea (Figs. 3, 9, 10, 70), belonging almost exclusively to the deep sea; hey furnish many of the luminous fishes of those regions. Almost ll of them are recognizable through their extended form, with dorsal and anal fins placed far to the rear, and through the rows of ights along their sides, inviting comparison, as Beebe said, with an ocean liner. The red and green lights, sometimes very large, which hey show below their well-developed eyes, and the luminous ilaments, sometimes very long, hanging from their chin or throat, re further characteristics of the Stomiatoidea, as are also the great eeth, sometimes immense, in mouths which they can open in-redibly wide. No doubt they prey insatiably on their fellow-reatures of the deep sea.

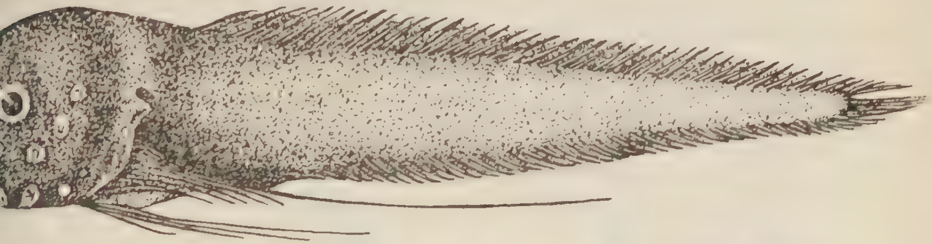


FIG. 72.—*Careproctus longifilis*, a deep-sea fish of the eastern Pacific, 3000 metres. Natural size.

Perhaps the most frightful of the Stomiatoidea is the viper fish (genus *Chauliodus*, Fig. 10), already mentioned. When its mouth is losed its great teeth project, as it cannot get them inside. But it is small fish, usually only about 6 inches long; an exceptional specimen may reach 10 inches. It has no chin-barbel; the place of this is taken by the greatly lengthened first ray of its dorsal fin. Satterlee's stomiatoid (*Eustomias satterleei*), with its short but bushy chin filaments, we know already; such branching barbels are characteristic of the genus *Eustomias* (Fig. 9). *Macrostomias longibarbatus* (Initial letter, Chapter IV) is caught at 1200 to 1800 metres below the surface in the East Atlantic and the Indian Ocean; its very long barbel ends in a light organ surrounded by feelers. In this species the pelvic fins are prolonged into feelers and end with swellings on the separate rays; these, too, may be presumed to be light organs. This fish is a foot long, and is therefore one of the larger members of this group, other members of which range between a foot and 5 inches in length. Dr Beebe, however, caught sight on one of his dives of a stomiatoid 6 feet long, a size never yet found in a net haul. He gives a vivid description of it (*Half Mile Down*, pp. 172-3).

"At 2100 feet, I had the most exciting experience of the whole dive. Two fish went very slowly by, not more than six or eight feet away, each of which was at least six feet in length. They were of the general shape of large barracudas, but with shorter jaws which were kept wide open all the time I watched them. A single line of strong lights, pale bluish, was strung down the body. The usual second line was quite absent. The eyes were very large, even for the great length of the fish. The undershot jaw was armed with numerous fangs which were illumined either by mucus or indirect internal lights. Vertical fins well back were one of the characteristics which placed it among the sea-dragons, Melanostomiatids, and were clearly seen when the fish passed through the beam. There were two long tentacles, hanging down from the body, each tipped with a pair of separate, luminous bodies, the upper reddish, the lower one blue. These twitched and jerked along beneath the fish, one undoubtedly arising from the chin, and the other far back near the tail. I could see neither the stem of the tentacles nor any paired fins, although both were certainly present. This is the fish I subsequently named *Bathysphaera intacta*, the Untouchable Bathysphere Fish."

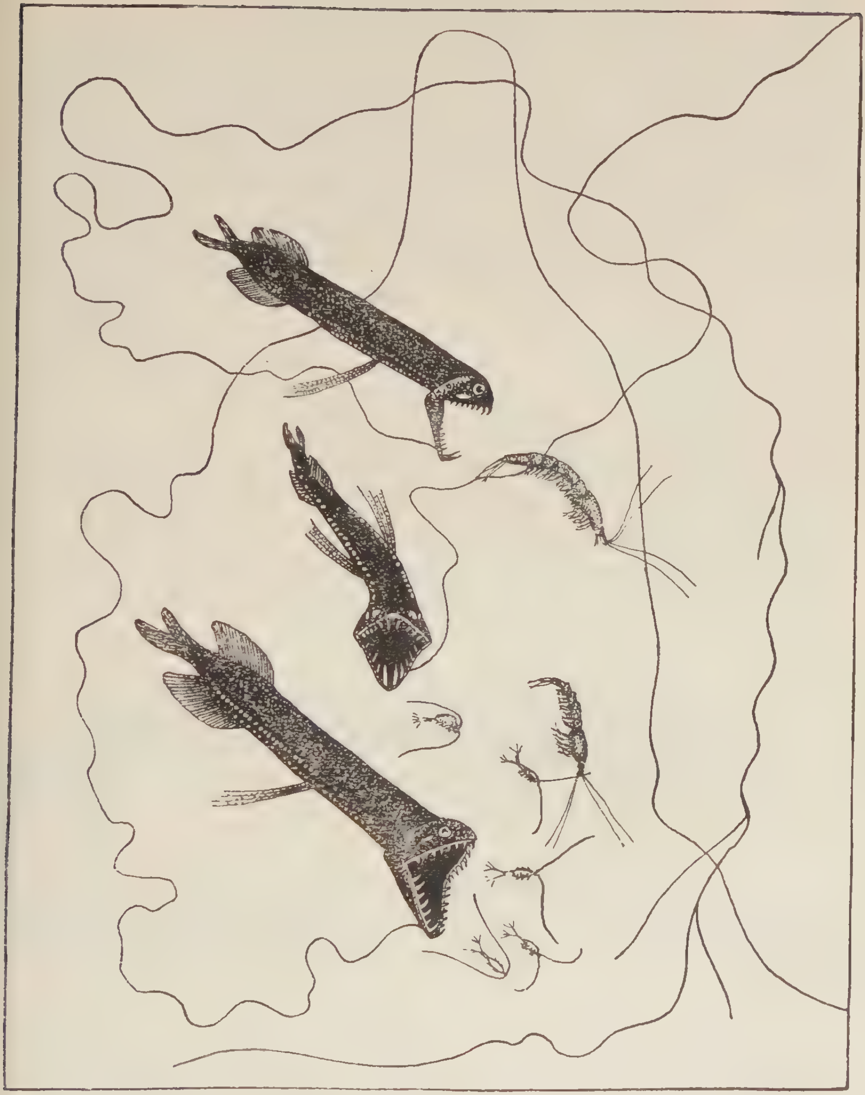


FIG. 73.—The deep-sea stomiatoid *Ultimostomias mirabilis* hunting for Rhizopoda. Off Bermuda, about 600 metres. Natural size.

A record in chin filaments was made by a stomiatoid caught off Bermuda in a net at about 1800 metres, *Ultimostomias mirabilis* (Fig. 73); its barbel was ten times the length of the fish. It is true that the fish was only an inch and a half long. It had the lights beside its eyes and the rows of smaller lights along the sides of the body which are characteristic of the whole family; and sections of its feelers seemed to glow. It is difficult to imagine what services the long barbel may render to *Ultimostomias;* during all the wriggling and little darting and turning movements which Beebe found to be characteristic of the stomiatoids, the fish will have to drag the long beard after itself like a towrope. Like the species allied to it, it has no pectoral fins.

The Cyclothones (Fig. 11) are also included among the Stomiatoidea. In his dives Dr Beebe does not seem ever to have noticed their many lights being put out. These are all fishes differing from most of the other stomiatoids in having small eyes which, in species living at great depths, can scarcely function. Some of the species are very frequently found.

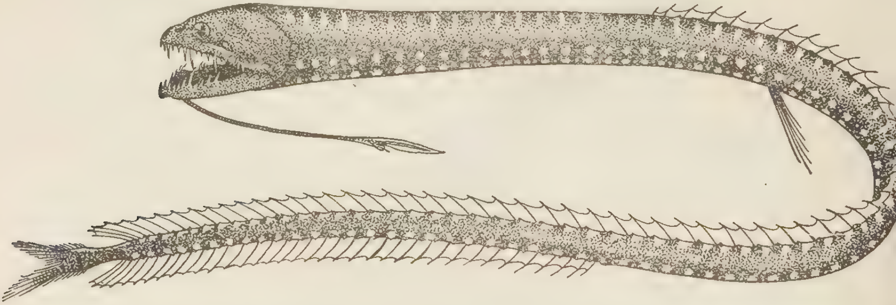


Fig. 74.—The deep-sea stomiatoid *Idiacanthus panamensis*, Gulf of Panama, 800 to 4000 metres. Almost natural size.

Very slender stomiatoids, again with huge teeth, are the members of the genus *Idiacanthus* (Fig. 74), which have been caught in great numbers at times. They are found in all the oceans at a depth of 500 to 1500 metres; at night they rise almost to the surface. They are remarkable especially for the strange form of their young: the delicate, almost transparent larvae of *Idiacanthus* are noted for the possession of eyes that for a time are at the top of uncannily long stalks, to which they owed their name, *Stylophthalmus paradoxus*, until it became known that they were larvae of *Idiacanthus*. As they grow the stalks are gradually drawn in, so that the adult *Idiacanthus* fishes have normal eyes at the sides of their head. This degeneration does not extend to the pliable cartilaginous rod that supports the eye-stalk; this rod is bent and pushed into loops and finally a knot, which ultimately has to be found room in special little capsules in the head, in front of the eyes (Figs. 75, 76).

This does not exhaust the peculiar features of these fishes. Their males remain much smaller than the females; they retain some of the features of the larva throughout their life, and as adults take no food; they seem to be concerned only to make what is certainly their one and only contribution to reproduction as soon as they can and then die. Their relatively large light organ in the cheek or eye must be a lure for the females (Fig. 77).

Finally, the hatchet fishes (genus *Argyropelecus*, Fig. 79), already described, with big shining silvery scales, belong to the sub-order of Stomiatoidea, as do also the small *Sternoptyx* fishes (Fig. 9), only an inch and a half long. Some species of hatchet fish have parallel upward-pointing telescopic eyes. The breast and belly of *Sternoptyx* have no scales, and are so transparent that the fin rays can be seen lying within; these fishes are also remarkable for their thickset appearance in front, with which we shall often meet among the deep-sea devilfishes.

The closely allied sub-order of the genuine salmon (Salmonoidea) also has some characteristic deep-sea members; among them are the big-eyed species of *Bathylagus* (Fig. 78), which, like *Idiacanthus* (Figs. 75, 102), have stalk-eyed larvae, and the genus *Winteria*, with telescopic eyes slanting forward and upward—and the astonishing *Opisthoproctus* (Initial letter, Chapter X), with an ill-shapen body suggesting rickets, and telescopic eyes pointing straight up.

To the order of Iniomi belong not only the blind species, already mentioned, of the genera *Bathypterois*, *Ipnops*, and others, but also

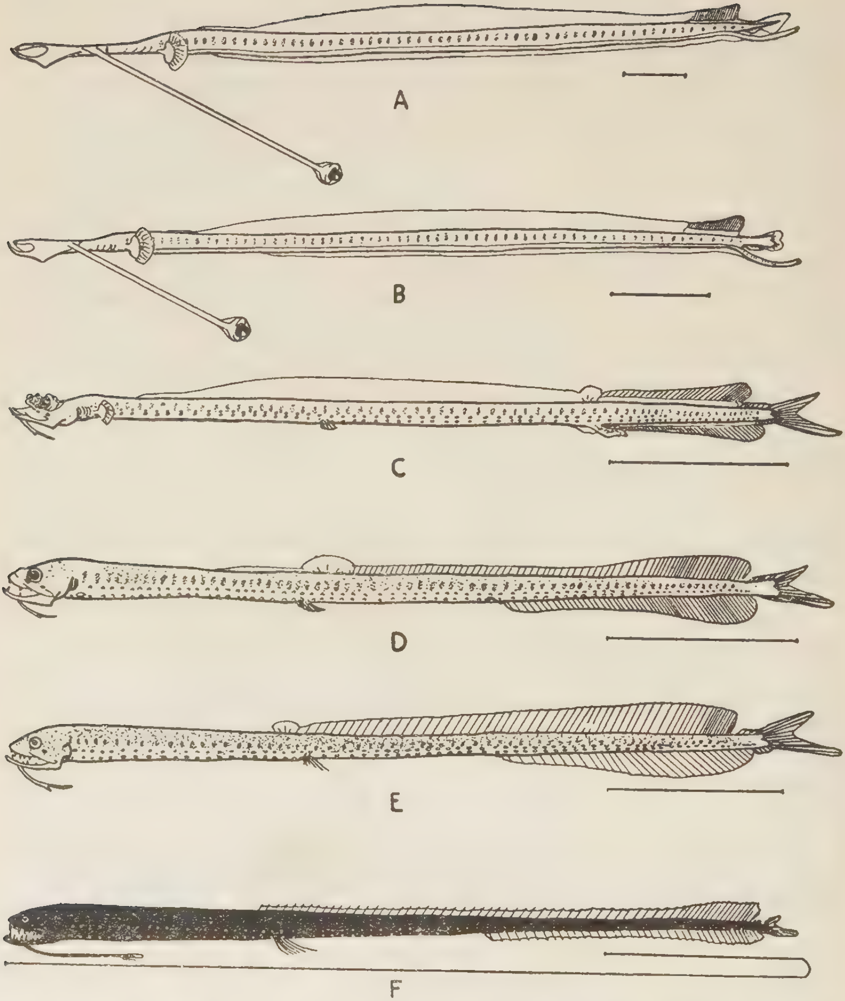


Fig. 75.—Stages of development of the deep-sea stomiatoid *Idiacanthus fasciola*. A, B: Young larvae of indefinite sex with tubular eyes (*Stylophthalmus paradoxus*), length 16 and 25 millimetres (three-fifths of an inch and one inch). C: Female larva immediately after atrophy of the tubular eye. Length 45 mm. D and E: Transition stages to F: the adult female, 267 mm. long. The black lines enable the lengths to be compared.

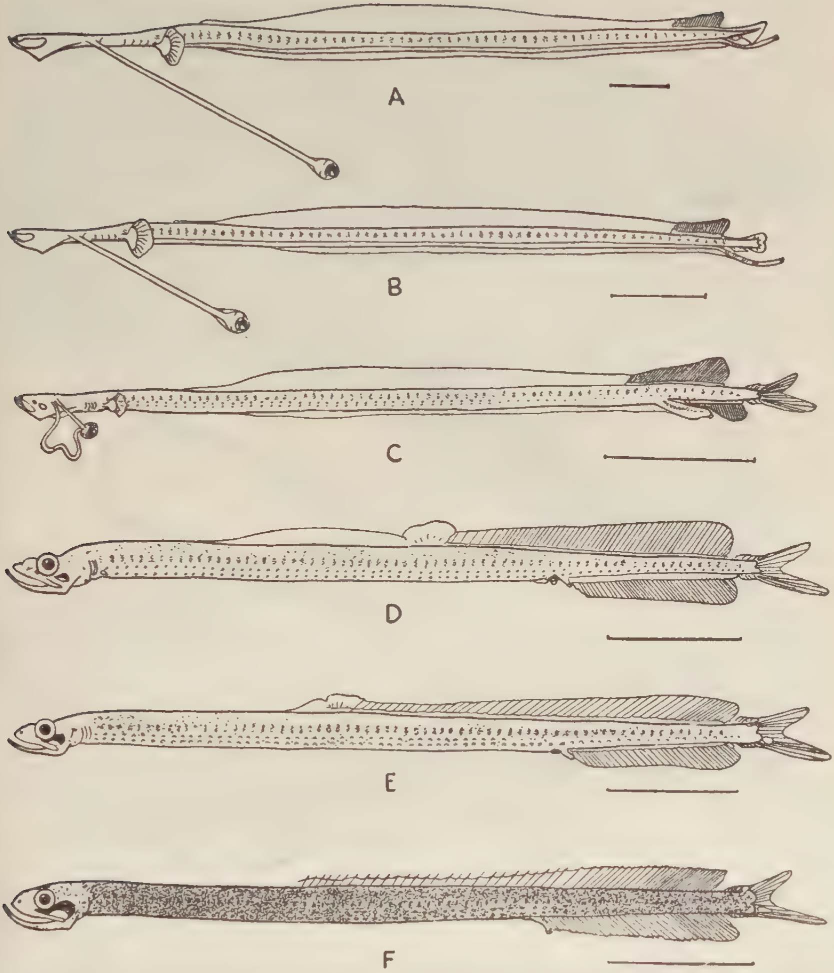


FIG. 76.—Development of stomiatoid *Idiacanthus fasciola*. A, B: Young larvae of indefinite sex, with tubular eyes (*Stylophthalmus paradoxus*); length 16 and 25 mm. C: Male larva with degeneration of the tubular eye; length 40 mm. D and E: Transition stages to F: the adult male, 38 mm. long. The black lines enable the lengths to be compared.

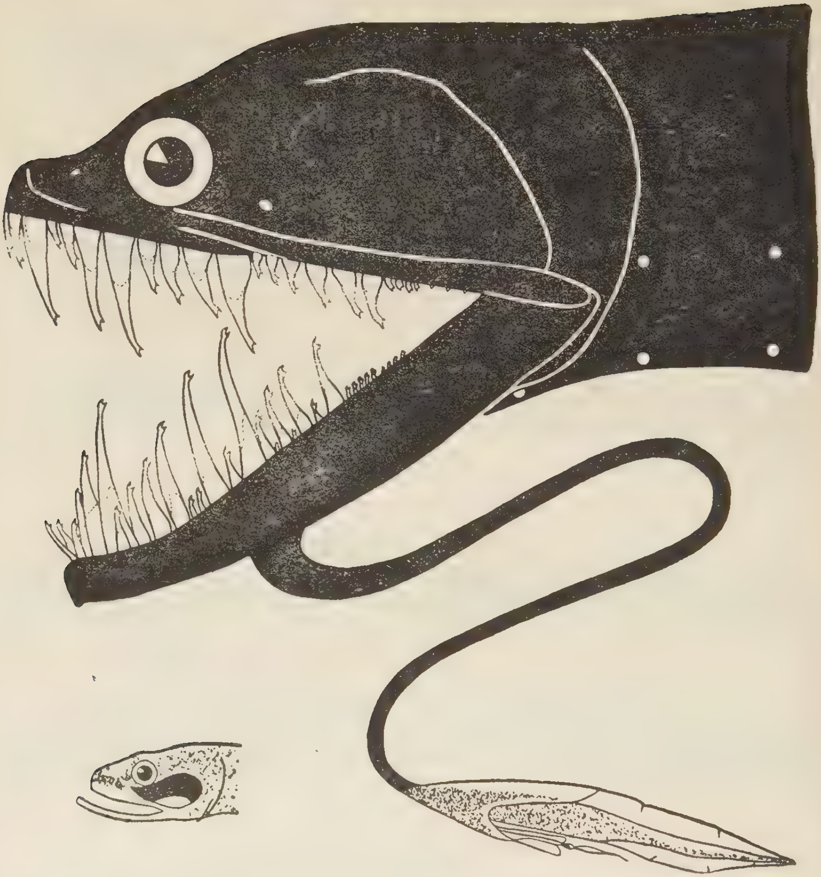


FIG. 77.—Heads of the adult female and the adult male of *Idiacanthus fasciola* for comparison. 5 times natural size.

the lantern fishes (family Myctophidae), (Fig. 11), referred to above, and the small species of the genera *Evermannella* and *Scopelarchus*, some of which have telescopic eyes. In many cases Myctophids can hardly be regarded as true deep-sea fishes in view of their marked inclination to move to higher levels, especially at night.

An independent order of fishes is formed, owing to its many peculiar features, by the giant-tailed genus *Giganturus* (Fig. 12).

Some species differing little from each other have been caught in the Atlantic and the Indian Ocean at depths between 1000 and 2000 metres; they are 5 to 8 inches long, and have horizontally protruding telescopic eyes. They have strong jaws that mark them as predatory fishes, and they are sometimes caught with fishes almost their own size in their elastic stomachs. The extraordinary size of the under part of the tail fin has given them their name. Finally, they are a striking exception among the deep-sea fishes (which are almost always of dull colour) in having a scaleless skin with a bright metallic sheen.

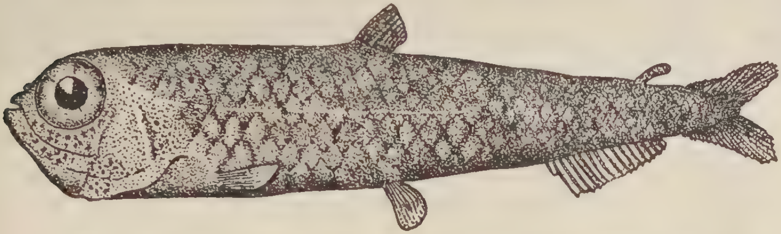


FIG. 78.—The deep-sea salmonid *Bathylagus benedicti*. North Atlantic, 2000 to 3500 metres. Three-quarters natural size.

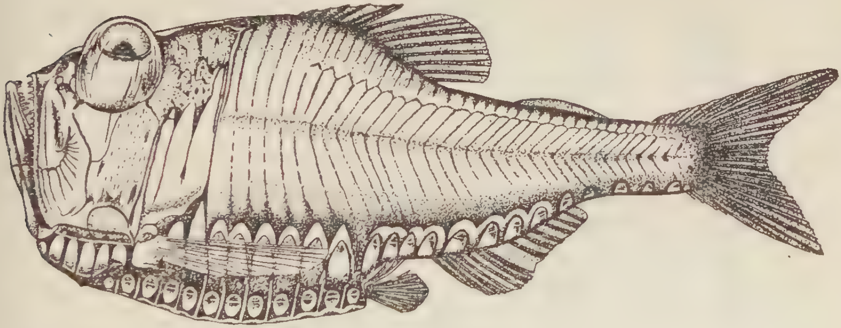
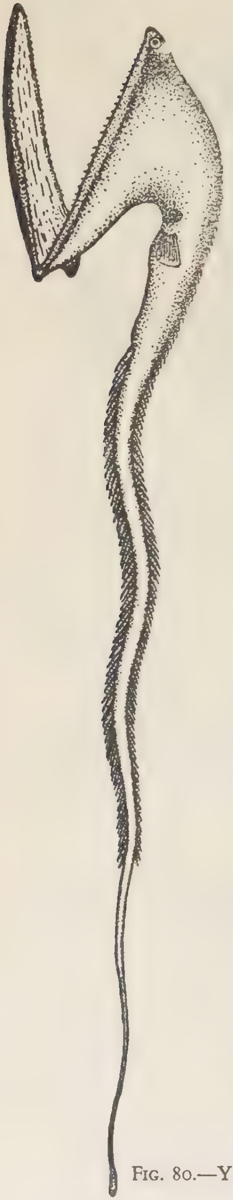


FIG. 79.—Hatchet fish *Argyropelecus affinis* with light organs, telescopic eyes, and scales with a silvery gleam. All oceans, 600 to 2000 metres. Natural size.

Strange as the appearance of many of the deep-sea fishes here mentioned may seem, they are excelled in this respect by the gulper (order Lyomeri, family Saccopharyngidae, Figs. 16, 80). These



gulpers live usually at very great depths in all the oceans. They are up to a yard long, and have an enormous head, with a grotesquely wide and deep mouth, capable of even further extension. Compared with that great head and mouth, the rest of their body often seems a mere thread-like appendage. This terrifying mouth has almost always, however, only small teeth; evidently this fish gulps down its prey without stopping to masticate it. Gulpers have, indeed, been caught, like the *Giganturus*, with creatures virtually of their own size, swallowed whole, in their stomach. At the end of their thread-like tail are light organs; their eyes are very small.

There are not a few deep-sea species of the eel family (order *Apodes*); their long and slender form, common to almost all of them, betrays their family connexion. Among them many of the snipe eels (Fig. 82; initial letter, Chapter I) are marked by the unexplained form of their long pliable jaws, ending in a long thin beak: the beak cannot be closed, for its upper and lower parts curve away from each other and diverge more and more widely toward the tip. In some species the tips are slightly thickened; the teeth are very small. It has been conjectured that the widely parted beaks serve these eels as feelers when they race after prey, like swallows, simply imbibing the small creatures they find. But the resistance of the water is much greater than that of the air, so that this form of food collection in the water is hardly conceivable. Whole deep-sea prawns, over 2 inches long, have often been

FIG. 80.—Young of the gulper or pelican eel (*Eurypharynx pelecanoides*). All oceans, below 1000 metres. Natural size.

found in the stomachs of snipe eels, and they could hardly have drifted in. Snipe eels are found in all the seas, and are up to a yard long; most of them have large well-developed eyes. A characteristic species often found at depths of 1000 to 3000 metres is *Borodinula infans*. The species *Cyema atrum* (Fig. 81), only 4½ to 5 inches long, is remarkable for its small size and very small eyes; it has not been found at less than 2000 metres' depth. But the narrow ribbon-shaped larvae of all true eels (Figs. 83, 84) keep to much smaller depths; some of them are of considerable length, and all are nearly or quite transparent. In the past they were named *Leptocephalus* as a genus, until it was found that these remarkable fishes were only the young of the eel.

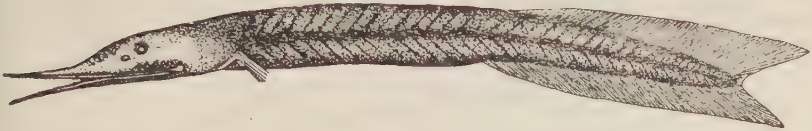


FIG. 81.—The deep-sea eel *Cyema atrum*. All oceans, 2000 to 3000 metres. Natural size.

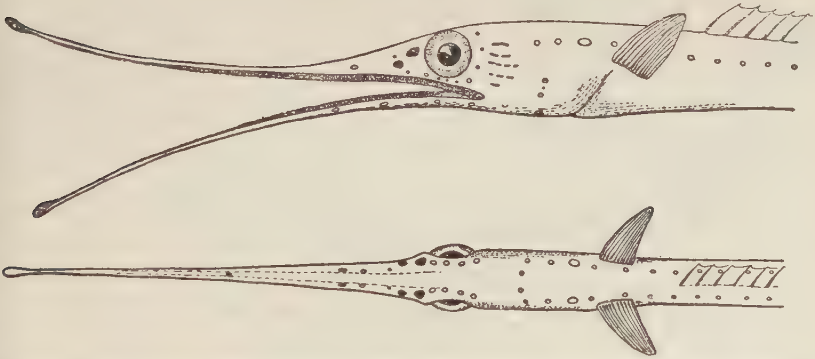


FIG. 82.—Head of the deep-sea eel *Borodinula infans*, from the side and from above. All oceans, (1000 to) 2000 to 3000 metres. Natural size.

The toothsome fresh-water eel grows out of such *Leptocephalus* larvae, and, incredible as it may seem, is a true deep-sea fish; every West European eel returns to the deep sea toward the end of its life. We shall return to the life-history of the eel, once one of the most mysterious chapters of animal biology.

Virtually all known bathypelagic fishes, those, that is, that swim above the bottom of the ocean, seem to be small fishes of 4 inches to a foot in length, only exceptionally reaching 2 or 3 feet. The reason may well be that as a rule only the smaller fishes are caught in our deep-sea nets, the larger ones escaping capture. As already mentioned, Dr Beebe and Otis Barton caught sight of fishes of considerable size at great depths, larger fishes than have ever been caught in nets, including a giant stomiatoid 6 feet long. Thus it is not surprising that some very big deep-sea fishes, 6 to 20 feet in length, and of highly impressive appearance, have so far eluded the nets of the deep-sea expeditions. These fishes are very rare, having been found only through mishaps that have driven them, in a more or less helpless condition, either to the surface of the water or, worse, on shore. They are representatives of the order Allotriognathi, the crested fishes, ribbon fishes, or scythe fishes, so called because they have on their head one or more long fin rays like crests, and because, though 6 to 20 feet long, they are only 8 to

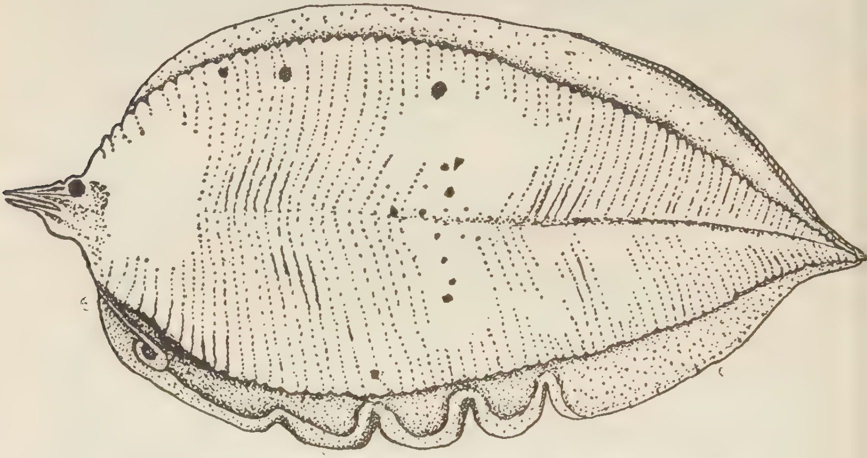


FIG. 83.—"Leptocephalus" larva of the deep-sea eel *Cyema atrum*. Length 56 mm. (2¼ inches).

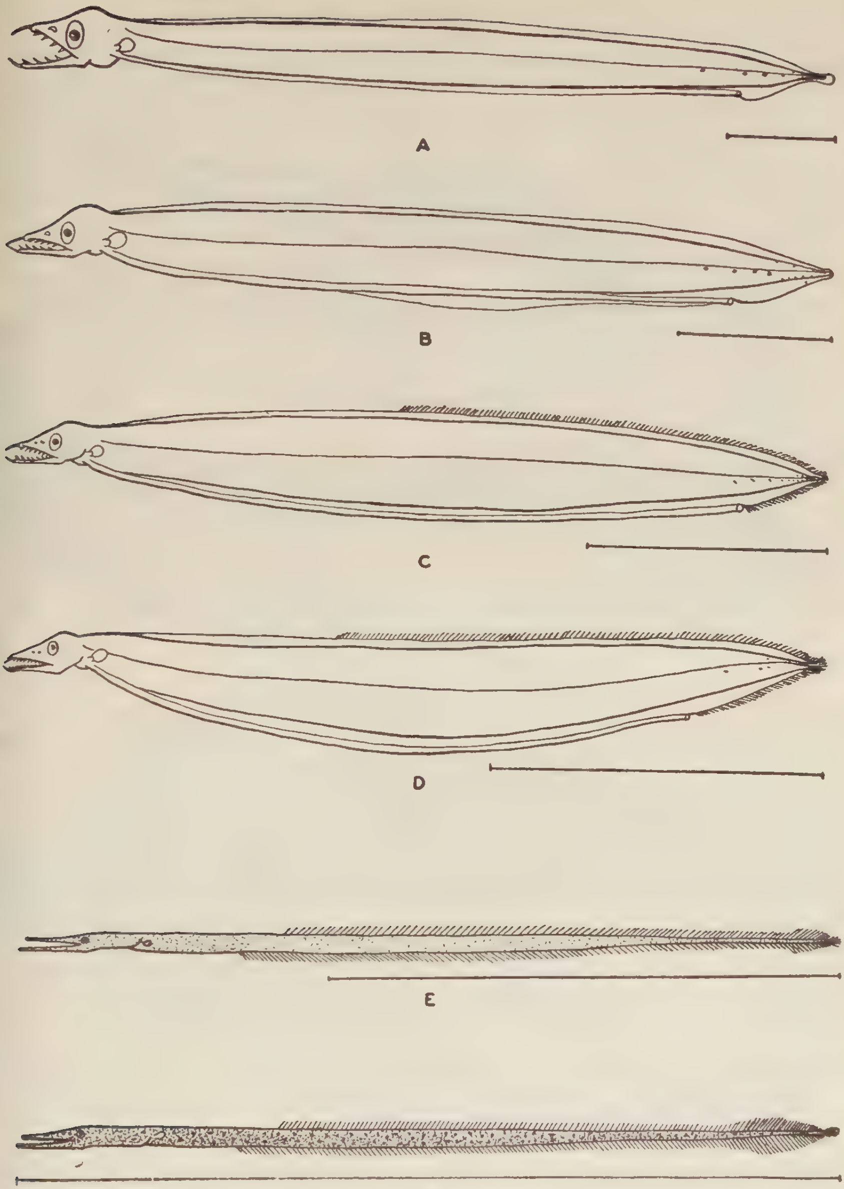


FIG. 84.—Development of the deep-sea eel *Platuronides acutus* (off Bermuda, 1500 to 2500 metres). A-D: "Leptocephalus" larvae 18, 26, 40, and 56 millimetres long (¾ to 2¼ inches). E: young eel, 92 millimetres (3½ inches). F: almost adult animal, 133 millimetres (5½ inches). The black lines enable the lengths to be compared.

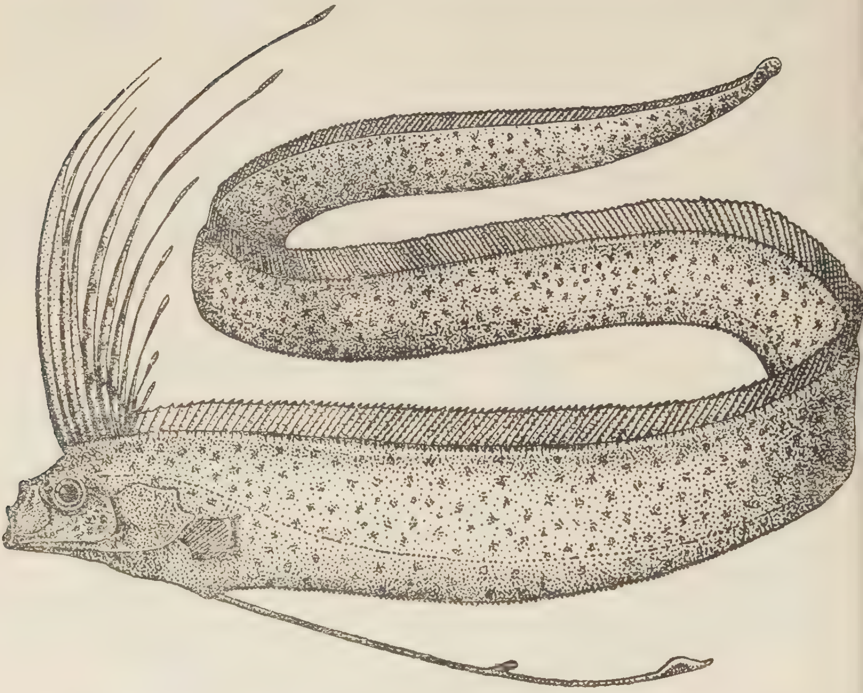


FIG. 85.—The king of the herrings (*Regalecus glesnei*), 1 to 6 metres long. Deep-sea fish, all oceans.

16 inches wide and only 1 to 3 inches thick. Most deep-sea fishes are dark-coloured, but these crested fishes are a silvery white with only a few dark spots and markings, and their fins and especially the crest on their head are orange-yellow or even pink or a flaming red. These fishes have been found in all the oceans, but only rarely and only a few at a time, when they have happened to come, no doubt through ill-fortune, up to the surface or on shore. Their slenderness and fragility may well account for their only being able to live in the still water of the depths, and they have usually been injured when found and suffering from the difference of pressure and from the effect of the waves; often they have literally fallen to pieces as soon as the attempt was made to lift them out of the water.

Once, however, any of these great fishes has come in fairly perfect condition to Western shores, as has happened in the Mediterranean, its beauty and rarity have always created a sensation. The largest species, *Regalecus glesnei* (Fig. 85), 20 feet long, is called "King's fish". Their clipped mouth, with weak teeth, suggests that the ribbon fishes live on small animals.

To the ribbon fishes belongs also the rare *Stylophorus* ("filament bearer", Fig. 121); it is just 3 feet long, and has telescopic eyes.

The deep-sea species of mucous-headed fish, of the order Berycomorphi (genera *Melamphaes*, *Caulolepis*, and others, Fig. 87), are notable for their big scales, their dark steel-blue colouring, and the canals, sometimes half covered, on their heads, containing

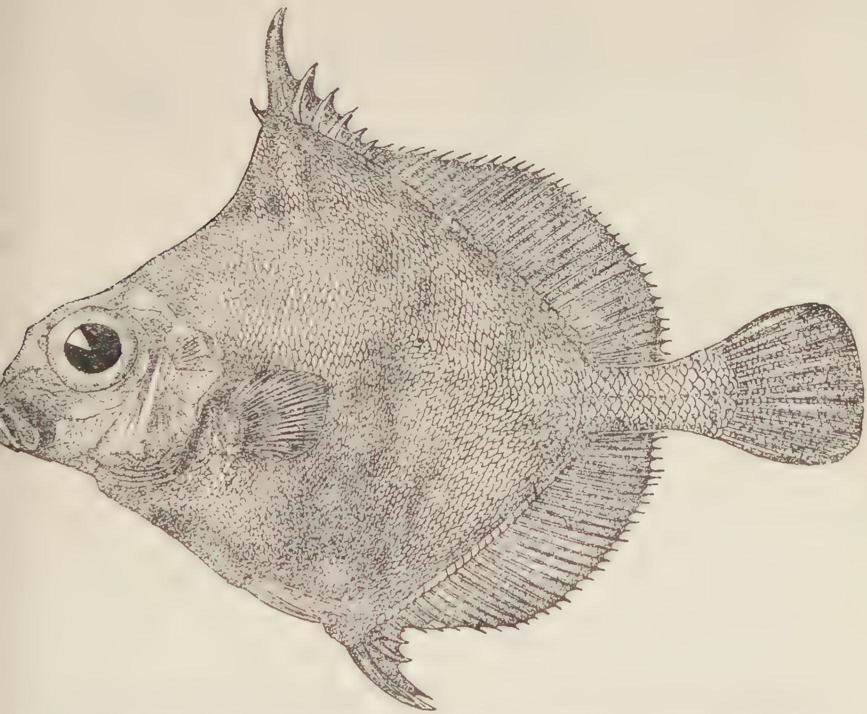


FIG. 86.—*Cyttosoma helgae*, a deep-sea fish of the eastern Atlantic, 800 metres. Nearly half natural size.

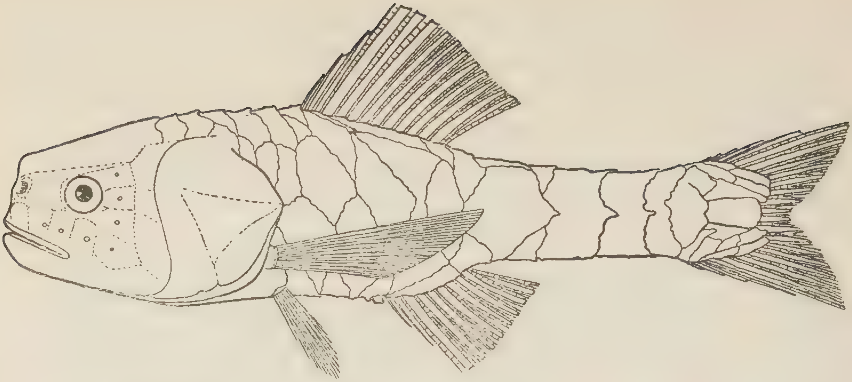


FIG. 87.—*Melamphaes mizolepis*, a deep-sea fish. Atlantic, 1800 to 3000 metres. 1¼ times natural size.

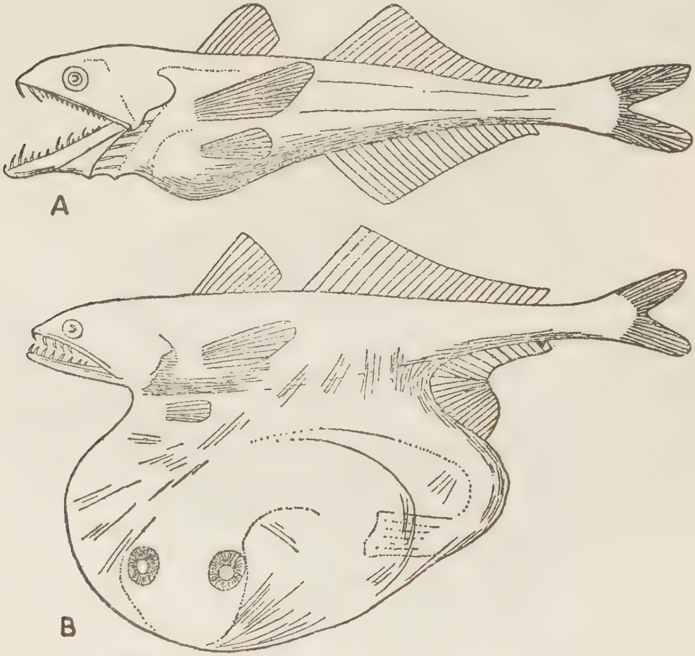


FIG. 88.—The deep-sea cross-toothed perch (*Chiasmodon niger*). Atlantic, 1000 to 3000 metres. A: normal condition. B: with great fish in distended stomach.

mucus, which may be luminous. They are usually only 2 or 3 inches long, and are found in all the oceans, sometimes in great numbers, always at great depths. Strange figures are all the slender and deep-bodied Peter's fishes (order Zeomorphi); among their members, which usually live in the upper regions of the water, the King of the herrings (*Zeus faber*) has some popularity among the maritime populations of the Atlantic and Mediterranean shores. The species of this order probably penetrated late and with hesitation into the deep sea; they are caught above the continental slopes at about 1000 metres.

We have already been surprised at the enormous distensibility of the stomachs of Harrison's gulper and *Giganturus*, but they are excelled in this respect by the *Chiasmodon* fishes (Fig. 88), of the order Percomorphi, allied to the perches. These deep-sea fishes, only 4 to 6 inches long, have often been caught or found drifting helplessly on the surface of the water with prey considerably bigger than themselves which they have swallowed whole. They then seem like a mere appendage on their incredibly swollen stomach; they have lost control of themselves, and have been carried by upward currents to the surface. The outline of their prey may be seen through the thin walls of their stomach. The problem remains how the little "cross-toothed perch" was able to overcome the monster.

Real monsters in shape and appearance, though often dwarfish, are the many deep-sea members of the family of the angler fishes (*Ceratioidea*, Figs. 15, 89–94, 119, 120, 122). Allied to them is the devilfish or angler, *Lophius piscatorius* (Fig. 124, B), familiar in European coastal waters, living at moderate depths; it is a flat benthal fish that lies half buried in the sand with a filament on its back, just behind its head, ending in a tuft-like thickening. Fishes approach this filament as it plays in the water, imagining it to be something to eat, and are themselves snapped up by the horribly wide mouth with its dangerous teeth; it swallows very big prey. The bat fishes, also belonging to this family, live in a similar way, as we have seen; many species belong to the archibenthal fauna, living on the floor of the continental slopes. These are all beasts of strange shape; the very name devilfish indicates the impression made by the angler fishes of the European coastal waters; but they are all outdistanced by the really incredibly grotesque and gruesome appearance of the pelagic deep-sea angler fishes. Most of these, it is true, are small, few as much as 8 inches long, and this tends to make them seem ridiculous or goblin-like rather than frightful; but some of them reach almost a yard in length. As a rule they are bunched up, almost globular, nearly as broad as they are long, and nearly a third of their length is taken up by their big head with the immense mouth and huge teeth. On the

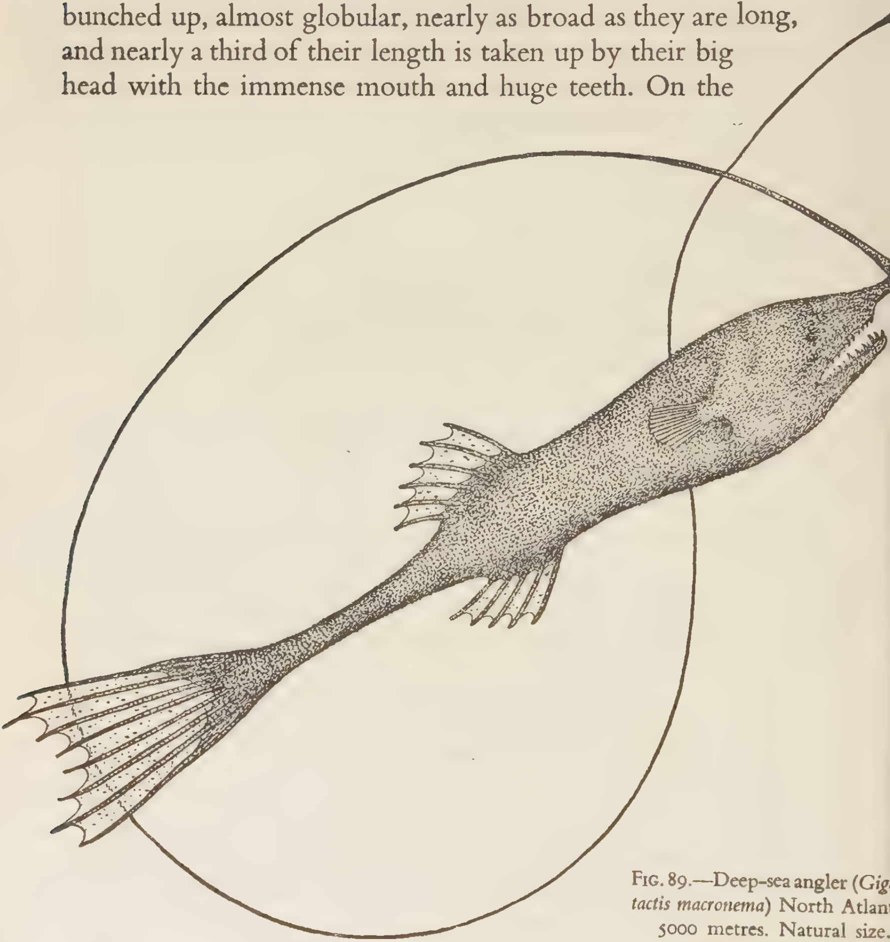


FIG. 89.—Deep-sea angler (*Gig*
tactis macronema) North Atlan
5000 metres. Natural size.

head is usually a fairly long and sometimes fairly thick filament, jointed. This ends usually in a light organ in the deep-sea anglers (which are pelagic, not benthal): the whole then has the appearance of a swaying lantern. Sometimes the lantern is on the back; it is a development of the first ray of the dorsal fin; it is well known that the first ray of the dorsal fin in many fishes is modified in a special way (Fig. 124)—particularly often into spines, which sometimes are supplied by poison glands, and occasionally into a tactile filament, as in the viper fish (*Chauliodus*, Fig. 10), or into suckers, as in the strange "ship-holders", which cling to other fishes and to the hulls of ships.

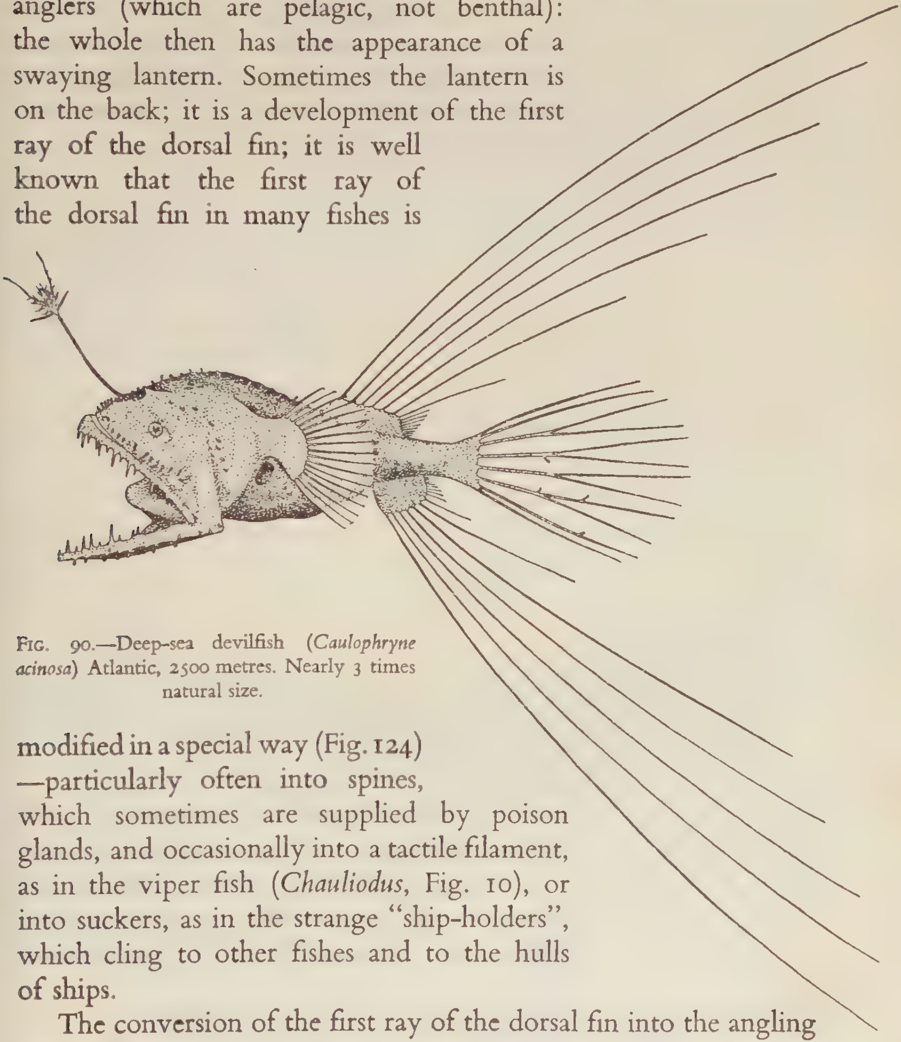


Fig. 90.—Deep-sea devilfish (*Caulophryne acinosa*) Atlantic, 2500 metres. Nearly 3 times natural size.

The conversion of the first ray of the dorsal fin into the angling line and lantern post of the deep-sea angler has had the most astonishing results, especially among the genera *Lasiognathus* and *Gigantactis*. In *Lasiognathus* (Fig. 119) the long and powerful back lantern is jointed in the middle, and at its end, in addition to the light organ, it has great hooks, looking like angling hooks; but it is doubtful whether they are so employed, for the very peculiar build of head and jaws of this strange fish suggests quite a different method of securing food. Among the species of the genus *Gigantactis* (Fig. 89), whose form suggests more activity and agility than the other deep-sea anglers, the lantern filament is almost at the tip of the snout, and may grow longer than the fish itself.

In addition to the lantern on their back, on the top of their head, or on the tip of the snout, some deep-sea anglers (genus *Linophryne*, Figs. 15, 92, 93, 124, C) have a long, usually thickly branched filament, perhaps luminous, on their chin. The thick leathery skin on the bodies of all these fishes is rough and full of warts and crinkles and folds, and sometimes protuberances and thorns; the fins are powerful and have thick rays; there are no pelvic fins. The eyes are often small; sometimes they point upwards, and then the great mouth opening is almost perpendicular (genus *Melanocetus*, Fig. 92). This makes the fishes seem so misshapen that they give an impression of hypertrophy and great helplessness. No doubt all these deep-sea anglers—probably with the exception of the genus

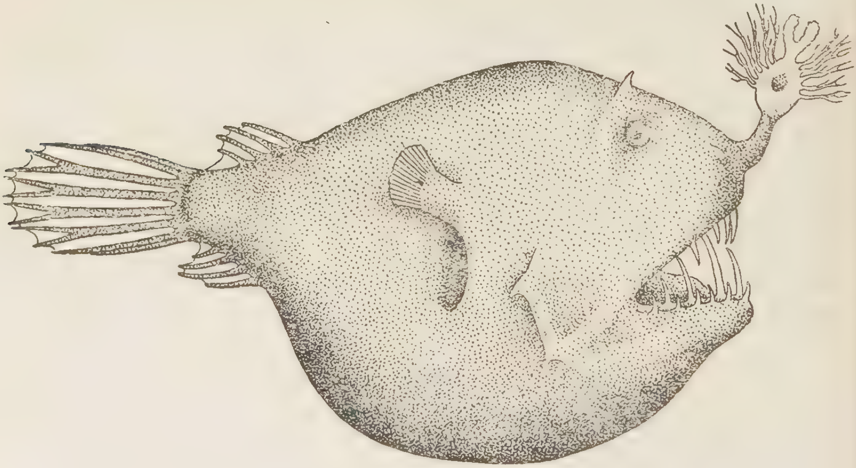


FIG. 91.—Deep-sea devilfish (*Borophryne apogon*) Pacific and Atlantic, 3500 metres. Natural size.

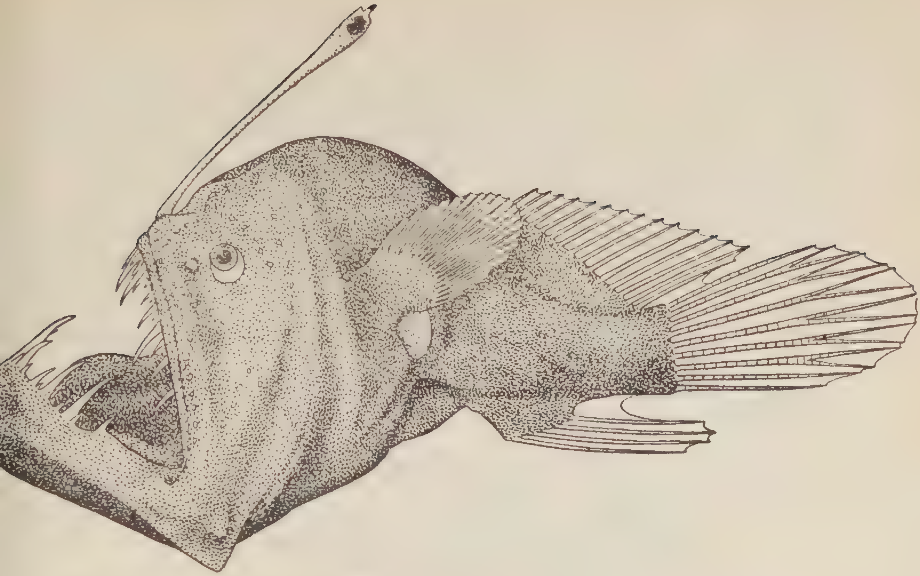


FIG. 92.—Deep-sea devilfish (*Melanocetus cirrifer*) Banda Sea, 3000 metres. 3 times natural size.

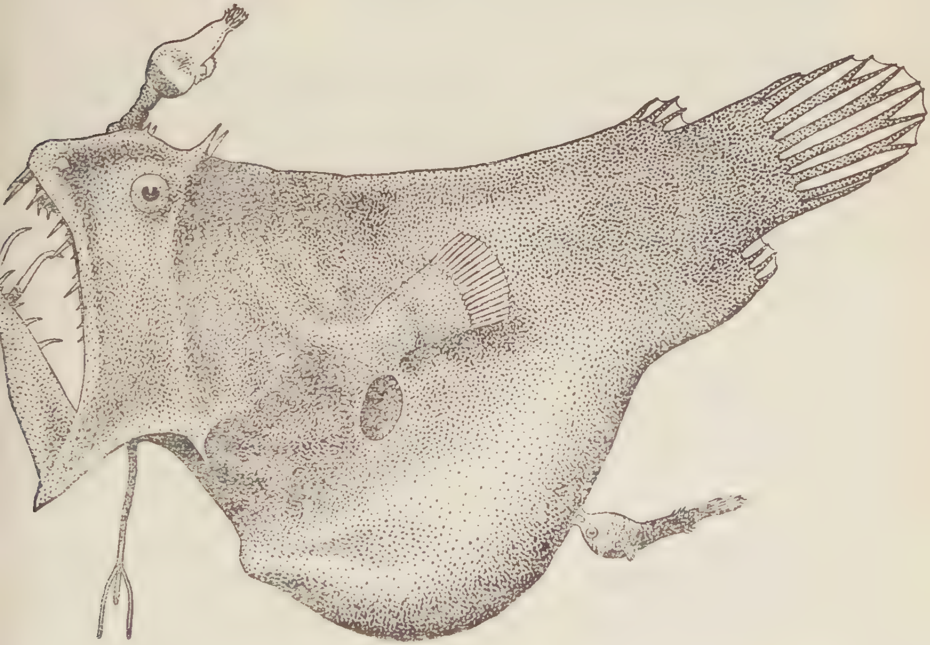


FIG. 93.—Deep-sea angler (*Linophryne argyresca*) with dwarf male grown on to it. Indian Ocean, 2600 metres. 1½ times natural size.

Gigantactis—can only move awkwardly and with effort; this is borne out by Dr Beebe's observations and by the behaviour of occasional deep-sea anglers brought to the surface alive.

These fishes must lure their prey with their swaying lantern—this has not actually been observed—and seize it, when it has come within reach, with a sudden snap of their mouth, which bristles with teeth.

A number of plump little fishes, only an inch to an inch and a half long, have been found in all oceans, of the genera *Aceratias* and *Rhynchoceratias* (Figs. 94, 123), allied to the deep-sea anglers, but without lantern or ray for it; they have, however, over-developed nasal organs and strangely formed jaws packed with teeth and in some cases pincer-shaped. It was discovered that these creatures are the males of the deep-sea angler fishes. The males, perhaps only in some species but perhaps at times in all, may enter a life-long compulsory marriage by holding on with their teeth to almost any part of the belly of the much bigger female; they then grow into the female with their jaws, and there actually develops a union of the blood circulation of male and female, so that the male draws sustenance, more or less like a parasite, from the female. To add to these immense peculiarities, while the first ray of the female's dorsal fin is converted into the angler fish's lantern filament, that of the male is so metamorphosed that it forms the upper jaw of the male's remarkable pincer-mouth (Figs. 123, 124, F, 135). All these features, almost incredible and in the vertebrates quite unique, are dealt with later in more detail and considered in relation to their biological significance.

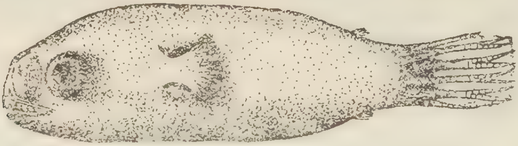


FIG. 94.—Dwarf male of deep-sea devilfish *Aceratias indicus*. Probably belongs to a female of the genus *Borophryne*, shown in Fig. 91. All oceans, 1000 to 3000 metres. 3½ times natural size.

CHAPTER X

BIOLOGICAL PECULIARITIES OF DEEP-SEA ANIMALS

Ecological principles – Thienemann's rule – Deep-sea animals' habits in movement and food collection – Water pressure, cold, and stillness of water as ecological factors – Main biocoenoses of the oceans as a function of the needs in regard to temperature and movement of the water – Adaptations – Lack of vitamin D – Blind deep-sea animals – Is there light on the deep-sea floor? – Telescopic eyes and stalked eyes – Light organs and light production – Chemical luminescence – The senses of touch and smell – The "rag-bag" process in food collection – The bottomless mouths of the dragon fishes – Spring-necked giant predators – Such marriages are made in the deep sea – The incredible transformation of the forward dorsal fin of the deep-sea angler fishes

Great privation is involved in the special conditions of existence in the deep sea, and hampers the development of life. It is the result of the one-sidedness, the monotony, and the extreme peculiarity of that region. One-sided biotopes with special conditions are generally subject to the ecological principle known as Thienemann's rule, which lays down that the more one-sided, the more special, and, so to speak, the more extreme a biotope has become, the poorer it is in species but the richer in individuals is its population, its "biocoenosis". For few species of animals will have the characteristics needed for life in a very one-sided biotope; but in it they will have scarcely any competitors and so will be able to increase enormously in populousness.

But for so inhospitable, so specialized a biotope there are exceptional cases in which Thienemann's rule does not apply. For one of the chief characteristics of the deep-sea biotope is the food scarcity that affects all its inhabitants without exception; we have already seen the reasons for it; but absolute lack of food permits no species to increase and multiply.

Darkness and cold in the depths seem by no means as serious adverse conditions as might be supposed. Complete blindness, for instance, and absence of any colouring matter in the skin, such as are found almost always in animals living in completely lightless caves and cave waters, are seldom observed in deep-sea animals. And, indeed, the deep sea does not merely contain a few representatives of orders and families and allied groups which generally live in shallow water or near the surface of the oceans; on the contrary, whole families and groups of genera of marine animals have made their way into the deep sea, and have there developed their individual form and character.

Most of the ecological relations existing quite generally between the deep-sea animals and their biotope are characteristic in essentials not merely of that biotope but at least of the whole field of marine existence. Thus, when we distinguish in the deep sea between the regions inhabited by the benthal and the pelagic fauna, the dwellers on the bottom and the animals that swim or drift in the sea, the same distinction has to be drawn for the dwellers in shallow waters.

The further distinction between sessile and vagile creatures, those fixed to an object and those freely moving, of the bathybenthos, and that between planktonic and nektonic (drifting and independently swimming) animals of the bathypelagic zone, are just as applicable to the creatures in shallow waters. But it is easy to see that the sessile species of the benthal fauna and planktonic species of the pelagic fauna are separate categories of marine creatures: only water, unlike air, is a medium dense enough to hold nutrient matter in adequate quantity and size, so that animals can live and grow in that medium and count on a subsistence; it is also dense enough to enable small animals to drift in it through their lives without any effort of their own. In the air and on dry land there can be no pelagic or planktonic animals.

An animal and the particular environment inseparable from it form a complete and balanced system of mutual relationships, which

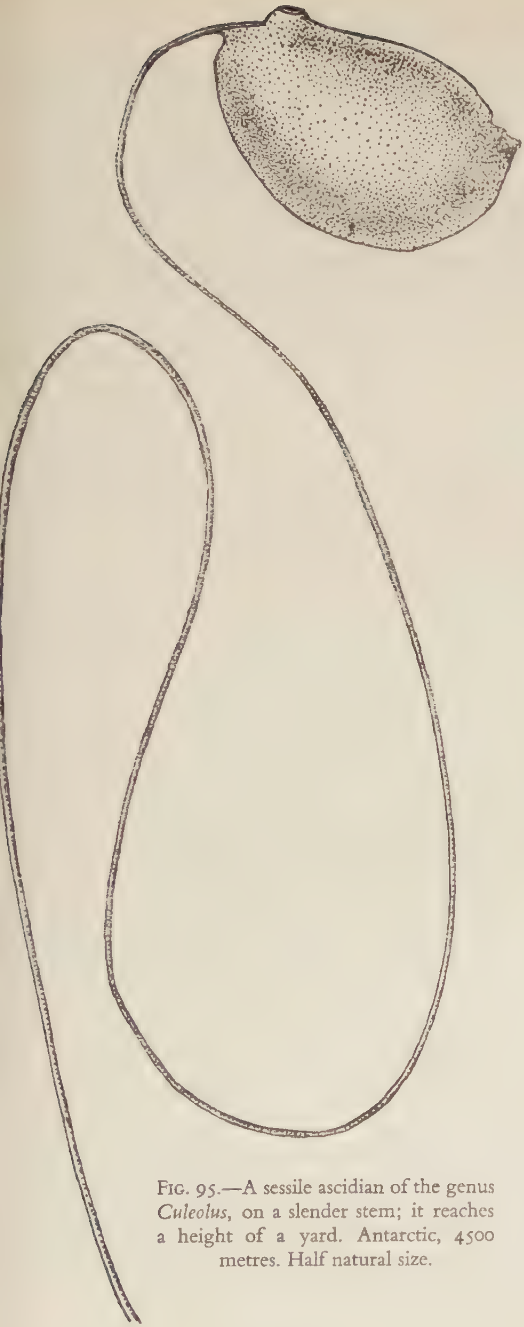


FIG. 95.—A sessile ascidian of the genus *Culeolus*, on a slender stem; it reaches a height of a yard. Antarctic, 4500 metres. Half natural size.

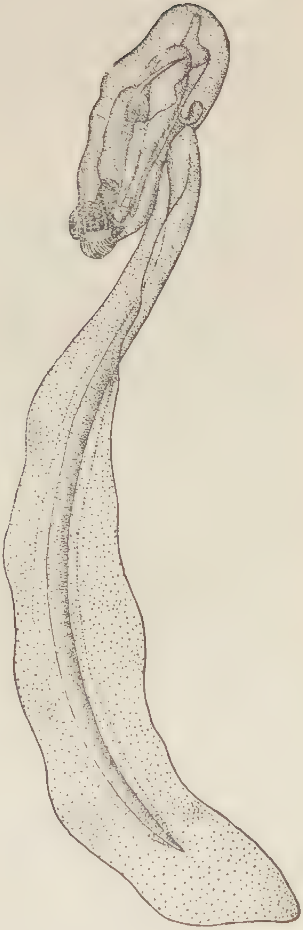


FIG. 96.—The largest known species of the tailed tunicates, *Bathochordaeus charon*. Side view, without shell. South Atlantic, 2000 metres. 1⅛ times natural size. Compare Fig. 22.

are complementary and influence each other, and by which the animal is enabled to live. We have then, more or less, in the choice presented with reference to that fundamental aspect of the movement of deep-sea animals in their medium of existence, brought into relationship two of the many ecological dimensions existing for them, namely, the "ecal", that is to say the dimension associated with the environment, the alternative "bottom of the ocean or the open sea?" and the "autozoic", concerned with the animal—"mobile or sessile?" Another dimension of the ecological system of relations of the deep-sea animals would be that which concerns the fundamental features of their collection of food. They are a good deal more difficult to distinguish than those concerned with movement. A little arbitrarily, but with practical justification, we divide all deep-sea animals first into the three great groups of the eaters of the animal plankton and detritus, the ooze eaters, and the predatory animals and garbage eaters. Then the plankton and detritus eaters may be divided into "clutchers", "filterers", and "flushers". The clutchers are the animals that clutch small animals or remains that come their way, using their outstretched or slowly moving arms, tentacles, or filaments, and feeding on their captures. The filterers filter or strain particles of food from the water that passes through their gills mainly for breathing; they have special filtering equipment for this. The flushers pass the water through their body or their mouth, again by special means. The group of predatory animals and garbage eaters divides into the hunters and the garbage eaters. In this ecological dimension too the deep-sea animals show no fundamental difference from the generality of marine animals, but obviously filtering and flushing are confined to the medium of water and are only possible within it.

The ecological dimension of the behaviour of deep-sea animals in food collection is not always clearly covered by the classification here made; particularly the distinction between plankton eaters and large predatory animals cannot always be strictly drawn: some animals, such as the sea anemones, may be both at once; and for some animals the relative sizes of hunter and prey must be taken into account. But the plan serves our purpose; and if we keep in mind both the system of reference we have acquired between the environmental dimension "floor of the ocean—open water" and the behaviour dimension "sessile—mobile", we arrive at a rough characterization of "ecological zones", which we may apply to the various marine populations, those of the breaker zones and the coral reefs, or those of the high sea and the deep sea, populated almost always by different species but always with similar characteristics (Table 6).

We begin in this way to gain an insight into the multiplicity and complexity of the dependences and conditioned states existing within the general system of ecological relations. In a further and more detailed application of our table we should be helped by it to arrive at an establishment of "ecological niches", that is to say, the particular total combination at any time of conditions of existence for each individual species of deep-sea animals. The concept of "ecological niches" is quite as important to our conception of biological equilibrium and of Nature's housekeeping as that of the biotope or the biocoenosis.

We said above that scarcity of light or complete darkness, scarcity of food, cold, and the stillness of the water were the principal characteristics of the deep-sea biotope. It is above all with the first two elements that the great majority of the most striking peculiarities of form and equipment among the denizens of the deep sea are connected. We shall see, however, that these are sometimes found in animals that do not belong to the deep sea, and, on the other hand, that they are by no means equally or even comparably developed among all the deep-sea animals themselves; indeed, some striking features, for instance telescopic eyes, are developed only occasionally, and as if by chance, among species of animals whose closest relatives are without them.

We said almost at the outset that growing water pressure in the deep water, soon becoming enormous, was countered by the deep-sea animals by no special development, although it might have been supposed that the water pressure is one of the greatest obstacles to

TABLE 6

Classification of deep-sea animals according to their mobility and their collection of food

(Ecological system of relations of deep-sea animals in the behaviour dimensions for movement and acquisition of food)

		Eaters of plankton and detritus			*Mud eaters*	*Predators and detritus eaters*		
		Clutchers	*Filterers*	*Flushers*		*Hunters*	*Lurkers*	*Detritus eaters*
Deep-sea animals dwelling on the floor of the ocean ("Bathybenthal")	Deep-sea animals firmly attached to the floor of the ocean ("sessile")	Polyps Sea anemones Corals Sea lilies Worms (Tube worms, Serpula)	Mussels Sea-squirts	Sponges Cephalopods Barnacles			Sea anemones	
	Deep-sea animals roaming on the floor of the ocean ("vagile")	Sea cucumbers of the family of the Cucumariidae			Worms Sea cucumbers Sea urchins Mussels Snails Crustaceans Some fishes	Starfishes Octopods Nautilus Crustaceans Fishes	Sea urchins Octopods Crustaceans Bat fishes	Crustaceans Sea urchins Fishes

Deep-sea animals swimming or floating in the water ("Bathypelagic")	Swimming or drifting (planktonic) deep-sea animals	Jelly-fishes Siphonophores Sea gooseberries Band worms Pelagic sea cucumbers (*Pelagothuria*) Small cephalopods (e.g. family Cranchiidae)	Copepods Ostracods Tailed tunicates Salps	Radiolaria Shelled pteropods		Heteropoda Naked pteropods		
	Independently swimming (nektonic) deep-sea animals		Fishes: deep-sea anglers, genera Lasiognathus and Thaumatichthys			Heteropoda Cephalopods Prawns Fishes	Fishes (deep-sea anglers, gulpers)	

life in the deep-sea biotope. But owing to the balancing of external and internal pressures the water pressure is no more felt by the deep-sea dwellers than the pressure of the atmosphere is by human beings. Deep-sea creatures can even endure considerable changes of pressure so long as the change is sufficiently gradual to permit adjustment to it. The amount and the variation of the water pressure are more important to possessors of a swim-bladder, the hydrostatic apparatus so widespread among the fishes of the surface layers, enabling the fishes to float or, by varying the gas content, to rise or sink in the water. The possession of a swim-bladder makes fairly rapid changes of pressure, especially rapid reduction, dangerous for a fish, as the bladder permits only very slow adjustment of pressure; sudden expansions of the bladder, the phenomenon of the so-called "bends", result from the sudden and violent hauling of a fish up to the surface. In the deep sea not a few fishes have swim-bladders, especially (strangely enough) benthal fishes; they do not rise so quickly as to suffer from their swim-bladder. How far the bladder of the fishes of the bathypelagic province, for instance, many allies of the salmon, is actually filled with gas or functions hydrostatically, remains an open question. It has been pointed out that at a depth of 1000 metres, with a pressure of 100 atmospheres, the gas content of the swim-bladder is compressed to one-fiftieth of the volume it would have at 10 metres down, and that more than three hundred times the energy is required at that depth than at 10 metres for the same lifting effect. This fact must reduce the undoubted biological advantages of the swim-bladder at the surface as a hydrostatic apparatus to an actual disadvantage in the deep sea, and this justifies the most serious doubt whether the swim-bladder functions at all below 1000 metres.

More general, though less striking at first, are the physical adaptations and peculiarities imposed on deep-sea animals by the other special features of their gloomy environment, the increasing cold in the depths, the relative stillness of the water, and the lack of calcium, especially in the great depths.

In all cases of such special features acquired by animals to enable them to cope with the special circumstances of their environment, in this case the deep sea, we speak of adaptation of the animals to their environment. It is better, however, not to associate with this conception the ideas of necessity and of the appropriateness of such adaptations, as was done in the past; for, as we have said, many animals manage without such adaptations, and of two closely allied species of the same genus, both living in the same way, in one the adaptations may be well developed and in the other entirely absent. Thus these adaptations are often not necessary changes, but merely changes made possible by the ecological system of the species or family concerned, changes which at a more advanced stage of development of the species or family may become biologically important and have an influence on natural selection.

Deep-sea animals need no external means of adaptation to the low temperature of their environment; they are all "cold-blooded", or rather with a body temperature dependent on that of the medium in which they move, so that protection from cold would be of little service to them: protection is necessary and useful only where there is heating, and so in the animal world only for animals that themselves produce heat, that is to say, among mammals and birds, which have developed fur and feathers, or fat under their skin, and so on. Nevertheless, deep-sea animals must have other means of adaptation to low temperatures. In our aquariums we see tropical fishes sometimes perish although they are in water that is far above freezing-point, and on the other hand there are fishes that are not found in water of more than 1° C. There must be specializations and differentiations in the composition of the body fluids (and above all in the protoplasm as the chief component of the individual cells of the body), which determine the fitness or the preference of different cold-blooded animals for high or low temperatures. The nature of these specializations is almost entirely unknown; we distinguish between eurythermal and stenothermal animals, that is to say, those which can endure a wide or only a narrow range of temperature, as in the two cases referred to above. We shall see how for some deep-sea animals their stenothermy, their specialization for a narrow range of temperature in the neighbourhood of zero Centigrade, accounts for their remaining in the depths of the oceans. For such low temperatures are usually found only in the depths; in northern latitudes, where they are found up to the surface, such stenothermal animals are caught at quite small depths. In the depths, in contrast to the surface, there are gentle, even, often almost imperceptible currents; these, however, are continuous, and we have dealt at length with their importance to the food supply of the deep sea, and of the ocean in general. The relative immobility of the deep water favours certain special developments in the animals of all groups and classes living in it, which are widely but not universally found. One feature is the remarkable fragility of the skeleton and structural elements of the body, and of the shell and protective covering, of the deep-sea animals. Another is the occasional development of giant forms, such as the classes and orders concerned do not show except in the deep sea. Thus among the sessile animals on the floor of the ocean there are sponges (*Monorraphis*, Fig. 40) and coelenterates (*Branchiocerianthus*, Fig. 41; *Umbellula* species, Fig. 41) 6 feet high and over, and deep-sea Ascidias, sessile tunicates, that rise on swaying stems to quite unusual heights, for their species, a yard or more (species of *Culeolus*, Fig. 95). It has been said that sessile animals of the bathybenthos show a tendency to "grow up to meet the rain of detritus drizzling down to them". But this idea is developmentally and biologically unsound; it is the character of the environment, the perpetually still water, that enables the sessile animals of the deep sea to attain such size. In disturbed water they would be doomed to early destruction. Similarly, the stillness of the water in the depths permits unusual growth of vagile benthal animals and members of plankton-eating families. We have seen that much the largest of the sea urchins, crabs, isopods, and sea spiders (Initial letter, Chapter VI), belong to the deep sea, as do the largest ostracods, hyperiids (Figs. 61, 97), swimming heteropods, and tailed tunicates (Fig. 96). In these groups too there are no species of such size to be found in the high sea, still less in the zone of the breakers. As the stillness of the deep sea makes possible the development there of giant forms that are fragile and delicate, so it permits the degeneration of all supporting and strengthening elements in the bodies of its denizens. In the deep sea the shells of unicellular Radiolaria and Foraminifera, the skeletal spicules of sponges and echinoderms, the shells of sea urchins, mussels, and snails, the bones of fishes, are often so thin and weak and scarce that they would give no support or protection in disturbed water. The biological significance of such degeneration of skeletons and supporting elements lies in the saving of material thus made possible, a saving of which they stand in urgent need, since skeletons and shells need calcium, and below 2500 metres the water is so deficient in calcium that that element dissolves readily in it, so that it becomes very difficult for animals to build up and maintain calcareous structures.

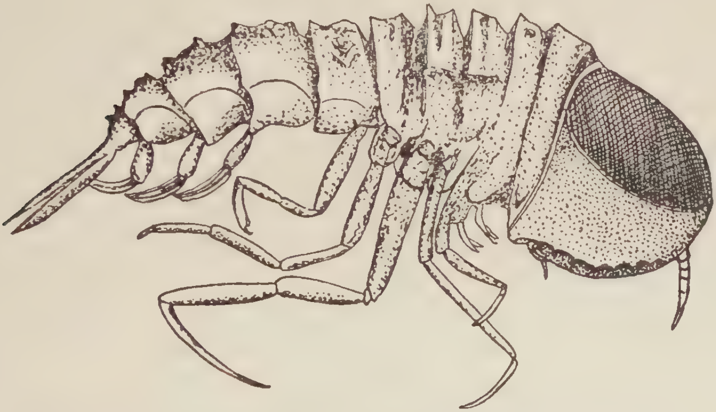


FIG. 97.—The "wondrous-eyed hopper" (*Thaumatops magna*) the largest known hyperiid crustacean. Atlantic and Indian Oceans, 2500 to 5000 metres. Natural size.

Another widespread peculiarity in animals of the bathypelagic zone, made possible by the motionlessness of the deep water, is the exceptionally loose, gelatinous, and aqueous composition of their tissues. We see this in some of the plankton animals, such as jellyfish, marine worms, and others, in the surface layers of the ocean; but it is to be found also in groups of creatures in the deep sea whose allied groups do not show it elsewhere—very strikingly, for instance, in squids and in true fishes. This looseness and delicacy of the tissues in the deep-sea dwellers of these orders results in a virtual impossibility of bringing them to the surface undamaged, and it is clear that this fragility makes it impossible for them to live outside the still water of the depths. We mentioned this in the case of the deep-sea cephalopods of the genera *Amphitretus* (Fig. 67), *Bathothauma* (Fig. 65), and *Cirrothauma* (Fig. 100), and the Cranchiidae family (Fig. 64); but it is carried sometimes to almost uncanny lengths in deep-sea fishes such as the stomiatoids (Fig. 74) and even the great King of the herrings (Fig. 85). A small deep-sea angler-fish of the genus *Haplophryne* is also almost hidden with its fins, its back tentacles, and its eyes covered by a skin enveloping it like a thick layer of jelly (Fig. 98). The biological significance of this peculiarity permitted by the motionless deep water lies in the reduction of the specific gravity of these loosely built aqueous fishes, which hardly exceeds that of the water itself, and in the great increase effected in their surface, increasing the advantage drawn from the resistance of the water due to its viscosity, as explained above: both features increase the ability of the species in question to float in the water.

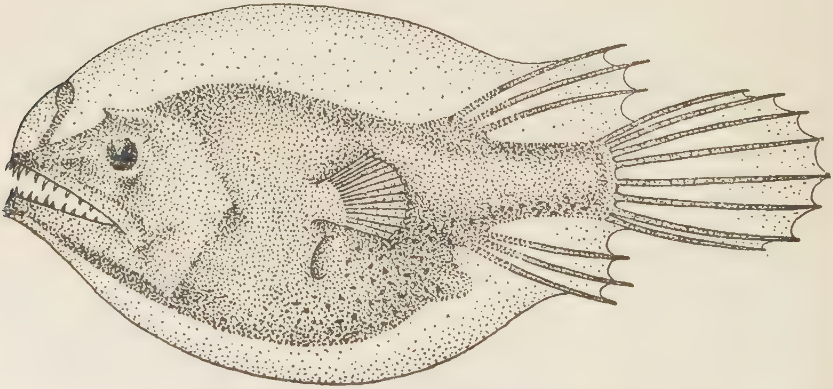


FIG. 98.—Deep-sea angler of the genus *Haplophryne* (?), with thickened gelatinous, translucent skin. North Atlantic, 300 metres. 3 times natural size.

From time to time animals whose peculiarities of bodily structure fit them for life in the great depths are found surprisingly near the surface. This happens, for instance, in Sagami Bay, in Japan, which is noted for the appearance there at a depth of 300 metres of animals found elsewhere only at 1000 metres or more; the essential condition is that the species in question can endure the higher temperature of the water at this level.

From the requirements of higher or lower temperature and still or moving water come two dimensions of the general structure of the ecological system of relations of marine animals. Placing these in relation to each other in the following table, we find at this very point a certain identification of the great communities ("biocoenoses") in the sea.

Very striking are many of the adaptations of deep-sea creatures to the shortage of light in their gloomy habitat. These consist mainly of special features in the development of the sense organs, especially the eyes, and then in the development, so frequently found, of a capacity of illumination, with special light organs, and finally of peculiarities of colouring. But before considering these we will touch on a physiological question raised by the lack of light in the deep sea. The formation and strengthening of all bones of vertebrates requires Vitamin D, a shortage of which produces symptoms of rickets; and Vitamin D can only form and function in the presence of light. In the deep sea, therefore, Vitamin D must either be lacking or at all events hindered by lack of its specific means of operation. It has thus been conjectured that the lack of Vitamin D accounts for the slightness and delicacy, already mentioned, of the bones of deep-sea fishes which was made possible by the stillness of the water in which they live, and that the same lack also accounts for the surprising lack of adequate bone in the vertebrae of some deep-sea fishes (Fig. 111), or for the curiously distorted forms of all hatchet fishes, *Opisthoproctus-salmler*, and some deep-sea devilfishes (Figs. 92, 93, and initial letter, Chapter X), some of which exhibit typical forms of rachitic malformation. But no more than a conjecture can yet be ventured; and naturally it is inconceivable in any case that these peculiarities of form could be remedied by increased supplies of Vitamin D.

TABLE 7

Classification of marine animals according to their requirements in regard to temperature and movement of the water

Description of communities

(Ecological system of relationships of the marine animals in the dimensions of their requirements in regard to temperature and movement of the water)

	Need of motionless water	*Need of moving water*	*No special requirements in regard to movement of water*
Need of higher temperatures	Community of still-water animals between the tropical coral reefs	Communities of the tropical coastal, shallow-water, and high-sea animals	Animals that appear indifferently in the breaker region and in the still-water region of tropical coastal and shallow waters
Need of low temperature	Community of the deep-sea animals	Communities of the Arctic and Antarctic coastal-water, shallow-water, and high-sea animals	Animals of the deep sea which appear in the Arctic and Antarctic oceans and also in the coastal and shallow-water zone
No special requirements in regard to temperature	Sun fishes (Fig. 126) (Deep-sea animals which also appear in still-water bays of warm seas at small depths)	Animals of world-wide distribution in the coastal, shallow-water, and high-sea regions of warm and cold seas	Animals found indifferently from coastal and shallow-water zones down to very great depths

Although below 400 metres the light is feeble, and below 600 metres it is imperceptible, blind animals, as already mentioned, are by no means frequent in the depths. This is the more remarkable since animals living in perpetual darkness, as in caves, are usually entirely blind. Since, then, most deep-sea animals have eyes, often very good ones or specially developed, we must assume that even the abysses of the oceans are not without traces of light. But there are plenty of blind denizens of the deep sea that are either entirely without eyes or have them in so atrophied a condition that they are no longer of use. The entirely blind animals are mainly benthal species, living on the floor of the ocean; they include almost all the members of the very ancient family Eryonidae, confined to the deep sea, among the long-tailed crustaceans (Initial letter, Chapter VII), with many of the isopods and some fishes, such as *Leucochlamys* and *Tauredophidium* (Fig. 99). But among these benthal forms it is certainly not so much the darkness of their habitat as their way of life, burrowing in the ooze and mud, that accounts for their loss of the faculty of vision. Freshwater animals that burrow in the mud, including such fishes as catfishes and eels, have only small eyes of little service, and pelagic burrowers in the ooze at relatively small depths may also be blind. And many fishes brought up from the remotest depths, fishes regularly taken from below 3000 metres, such as rat tails and sea lizards, species of the genera *Macrurus* and *Halosaurus* (Figs. 37, 38), have very good eyes, sometimes extraordinarily big. In this connexion we find the light organs of many bathypelagic fishes as a source of light for that otherwise completely dark region, but this does not apply to the bathybenthos,

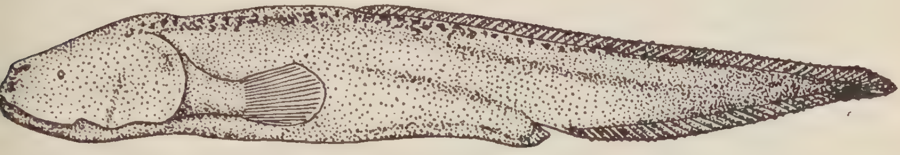


FIG. 99.—The blind and colourless deep-sea fish *Leucochlamys cryptophthalmus*. North Atlantic, 5000 metres.

for on the floor of the ocean, at all events in the deepest abysses, we know of no animals with light organs.

Whence comes the light that must exist actually in the deepest abysses, when many of the fishes living there have such well-developed eyes with which to perceive it? We do not know. Perhaps there are luminous bacteria in the depths, perhaps many of the animals there are luminous in spite of the absence of light organs. We find this frequently among the bathypelagic animals, and many of the striking mucus-canals on the heads of most species of *Macrurus* suggest that the light is due to illuminating substances which they may secrete. The great numbers, however, of deep-sea fishes that possess special light organs do not descend to the great depths, below 2500 metres, so that they can hardly contribute to their lighting. In those depths, too, there are freely swimming animals, not bound to the floor of the ocean, which are completely blind. We find them more frequently in the plankton of the bathypelagic region, where little copepods and ostracods, the larger hyperiid crustaceans and schizopods and prawns have lost their sight. These blind creatures have either no eyes at all or functionless eyes, with which they naturally cannot see.

Among the cephalopods only one blind deep-sea species is as yet known, the *Cirrothauma murrayi* (Fig. 100), from 3000 metres' depth in the North Atlantic, belonging to the eight-armed group and certainly not a benthal form.

Finally, there are bathypelagic fishes without eyes, or at all events without eyes that can function, such as those of the genera *Ipnops* (Fig. 69) and *Bathymicrops*, at least some species of *Cetomimus*, and the deep-sea devilfish *Typhloceratias*. All of these seem generally to keep below 2500 metres. Other fishes showing a preference for these considerable depths have degenerate and disproportionately small eyes but are probably able to make use of them—for instance, deep-sea species of *Cyclothone*, the gulpers, the genus *Bathypterois*, many deep-sea devilfishes, and others (Figs. 68, 80, 92, 93). It is a strange thing that even completely blind bathypelagic animals, like the octopus *Cirrothauma* and the fish *Ipnops*, have light organs, if the conjectures to that effect (they can be no more than conjectures) are correct. Even for these it may be important to use their lights, though they cannot see them, as a lure for their prey. But in the bathypelagic region animals with light organs are rare.

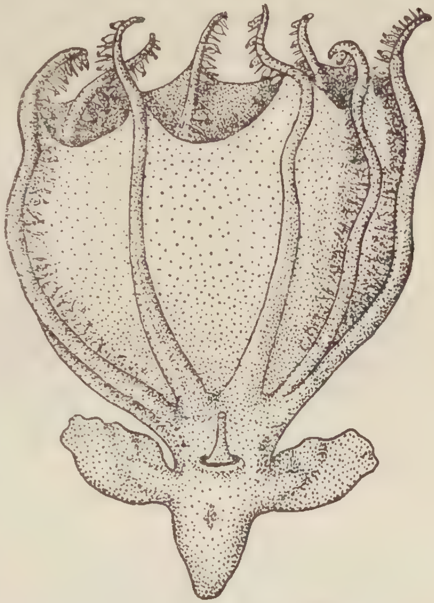


Fig. 100.—The blind deep-sea octopod *Cirrothauma murrayi*. North Atlantic, 3000 metres. Half natural size.

Further adaptations to the lightlessness of the deep sea, in addition to the loss or degeneration of the eyes, are their enlargement or special formation. As said above, this fact points inescapably to the conclusion that where deep-sea animals with such adaptations live, impressions of light must be received often enough and effectively enough to be regularly availed of, but that on the other hand the light must be too feeble to be perceived and availed of except with enlarged or specially formed visual sense organs. The sources of light are the last traces of sunlight at the lower limits of its penetration into the ocean, at a depth of about 600 metres, and below that the light produced by the deep-sea animals themselves. From the observations, quoted above, of the daring deep-sea divers William Beebe and Otis Barton, it was found that between 600 and 900 metres below the surface the ocean contains far more animals, largely self-illuminating, than might have been inferred from deep-sea hauls, and it seems as if the number of illuminated animals does not diminish before a depth of about 2000 metres is reached. The increase in the sensitivity of the eyes to light is usually secured by simply enlarging them, as is seen in many species of all sorts of different deep-sea animals. Among the invertebrates a particularly impressive example is the giant hyperiid *Thaumatops* (Fig. 97), which has the largest eyes of any known arthropod. Among the fishes the deep-sea salmonids particularly often have strikingly enlarged eyes, and so have most of the stomiatoids, many lantern fishes, most of the deep-sea eels, and many others (Figs. 11, 78, 82). It must be borne in mind, however, that most deep-sea animals have not enlarged eyes, or degenerate eyes, so that the deep-sea biotope requires neither degenerate nor enlarged eyes for its inhabitants. Considerably enlarged eyes are found, moreover, also in fishes that do not live in the deep sea.

A strange but rare change in the structure of the eyes in deep-sea animals are the so-called "telescopic eyes"; these eyes are usually pointed in the same direction, both receiving the same image. This is noteworthy because generally the eyes of fishes are at the sides of the head and have different fields of vision, and probably work independently of each other. The telescopic eyes of most fishes, and also those of the bathypelagic octopus *Amphitretus*, focus on a point, like human eyes. We know that this results in an enlargement of our field of vision and gives stereoscopic vision, and enables the distance of the object seen to be judged. We must assume that this faculty is possessed by those deep-sea animals which have focusing telescopic eyes, and that they draw biological advantage from this.

Telescopic eyes take their name only from their appearance, not from any faculty of seeing distant objects as if they were nearer. On the contrary, these eyes are particularly short-sighted, as the distance between their lens and the retina is increased. They do not come into existence simply through a lengthening of the eye, normally regarded as more or less spherical, but are formed through complicated shiftings of the lens and changes in the retina (Fig. 101) during the growth of the young fishes. The completed telescopic eye of the adult animal then forms a sort of central tubular section of a very large spherical eye; the possibility of focusing in order to see at some distance (the "faculty of accommodation") is very

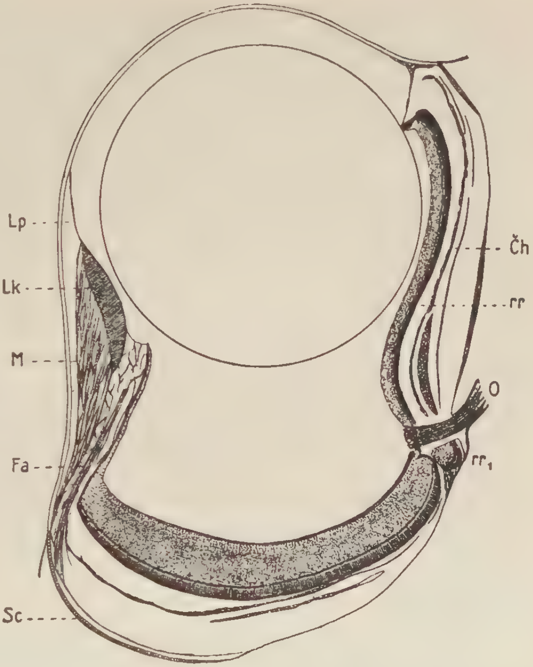


FIG. 101.—Longitudinal section through the telescopic eye of the adult deep-sea fish *Scopelarchus analis* (Atlantic and Indian Oceans, 600 to 4000 metres). O: optic nerve. rr, rrl: the part of the retina cut off and atrophied during the development of the telescopic eye; its main functioning section is in the floor of the eye. Ch: Chorioid membrance. Sc: sclerotic cartilage. Lp: reinforcement band for the "lens cushion" (Lk), which is moved by muscles (M) and enables the eye to be focused on a distant object. Fa: Fibres of the reflecting layer (tapetum). 25 times natural size.

slight. Whether the eye can actually perceive the forms of objects remains doubtful, and, indeed, improbable, since in any case the darkness in its owner's habitat can scarcely permit it. It may be conjectured that the special service rendered by telescopic eyes is to detect movement with some reliability and at the same time to secure a close estimate of the position of the moving object when it is at a short distance. This is certainly of importance to a slowly-moving predatory animal, dependent on lurking rather than on chase for capturing its prey. If the special equipment of its telescopic eyes enables it to estimate the rate of movement and the distance of approaching creatures accurate enough not to miss them when it snaps at them (and they will rarely swim straight into its mouth), the value of such organs of vision is obvious. For every failure to get hold of a morsel within reach may mean for the lurker in the depths a painfully long period of hungry waiting for the next victim.

Often the telescopic eyes point perpendicularly upwards. This may be connected with the fact that at the limit of the penetration of sunlight into the ocean the last traces of light can only be seen by looking straight up; they are no longer perceptible as diffused light, as Dr Beebe's observations showed.

Only a few deep-sea fishes, belonging to quite different families and genera, possess these parallel-set telescopic eyes; among those directly allied to the deep-sea salmonids, the genera *Dolichopteryx* (Fig. 103) and *Winteria*, among their rather more distant relatives, species of the strange Opisthoproctus (Initial letter, Chapter X), and some—not all—of the hatchet fishes (genus *Argyropelecus*, Fig. 79); also some, but again by no means all, species of the genera *Evermannella* (Fig. 138) and *Scopelarchus* (Fig. 101), which belong to the deep-sea lantern fishes (Myctophidae). There are also the genus *Giganturus* (Fig. 12), and the *Stylophorus* (Fig. 121). As we have seen, some of these have telescopic eyes pointing straight up, others have eyes slanting upward and forward, and yet others pointing straight ahead.

The telescopic eyes of the cephalopods, for instance, those of the bathypelagic octopus *Amphitretus* (Fig. 67), and of the crabs, have developed rather differently from those of the fishes, but biologically they certainly have the same significance. The deep-sea schizopod *Stylocheiron suhmi* has arrived at a strange, decided division of labour for its eyes. Each eye has a long section stretching forward in the fashion of telescopic eyes, for seeing in the dark, and a section adapted for seeing in the light; the light needed by this latter section is provided by a light organ lying within the eye.

Some fishes and cephalopods in the deep sea have another special device, eyes on stalks, clearly for service in the deep sea, in some definite but quite unknown connexion. These have not been found in many species, and it is a curious fact that they are found mainly in larvae, scarcely ever in adult cephalopods and never in adult fishes. The most striking are the eyes of the "stalk-eye" *Stylophthalmus*, the larva of the various *Idiacanthus* species (Figs. 75, 76), mentioned above; and larvae of some other genera, including the deep-sea salmonids *Bathylagus* (Fig. 102) and *Trachypterus*, allied to the ribbon fishes, have been found with stalk eyes, while the adults all have normally formed eyes. Much the same is true of several squids of the family Cranchiidae; the *Valdivia* Expedition found a number of stalk-eyed larvae of bathypelagic cephalopods, the adults having normal eyes. An exception is made by the *Bathothauma lyromma* drawn farther forward in Fig. 65, with strongly stalked eyes in the adult animal as well. Quite unique is the position of the stalk-eyes in the cranchiid *Sandalops* (Fig. 104), living in the deep water of the South Atlantic. Its eyes point in the same direction, but obliquely downwards. This position, found nowhere else in the whole realm of the cephalopods and fishes, has been associated with the assumption that *Sandalops* swims with its body slanting upwards, an equally unique position. So far only quite young animals of this genus have been found, and it may be that the adults have quite a different formation and direction of the eyes.

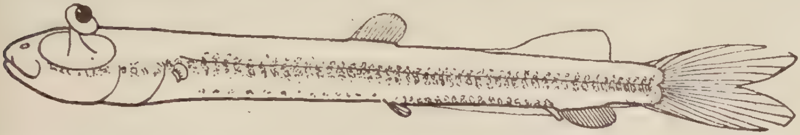
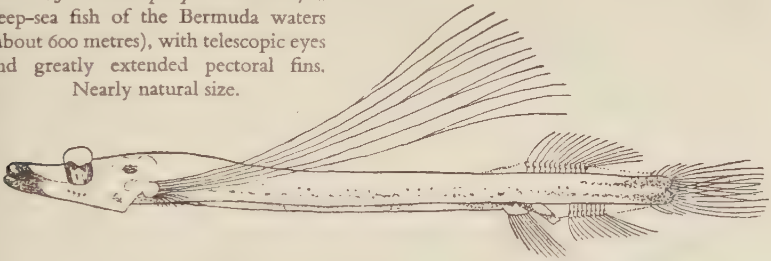


FIG. 102.—Stalk-eyed larva of the deep-sea salmonid *Bathylagus glacialis* (off Bermuda, 800 to 1000 metres). 5 times natural size. Cf. Fig. 78.

FIG. 103.—*Dolichopteryx binocularis*, a deep-sea fish of the Bermuda waters (about 600 metres), with telescopic eyes and greatly extended pectoral fins. Nearly natural size.



Stalk-eyes are quite usual in crabs, and our fresh-water crayfish has them; but deep-sea crabs sometimes possess extraordinarily long eye-stems, such as have not been observed outside that biotope.

Finally, a significant peculiarity of the eyes in deep-sea fishes is the scarcity or the complete absence of cones in them. In the visual organs of the vertebrates we distinguish two sorts of visual cells—the cones, which serve for seeing in the light and for distinguishing colours, and the "rods", used for seeing in the dusk and unable to distinguish colours. Certain complicated shiftings of pigment and cells in the back of the eyes put the cones out of action in the dark and the rods out of action in the light: the eyes assume the "bright" or the "dark" position; our human eyes do this, and simple experiments can make certain differences between vision with the cone cells and the rod cells realized with surprising vividness. The eyes of deep-sea fishes contain, however, only rods, that is to say, cells giving vision in dusk and scarcity of light, and their eyes are always at "dark". The only exceptions are those deep-sea fishes which habitually visit higher regions of the water which are well lit.

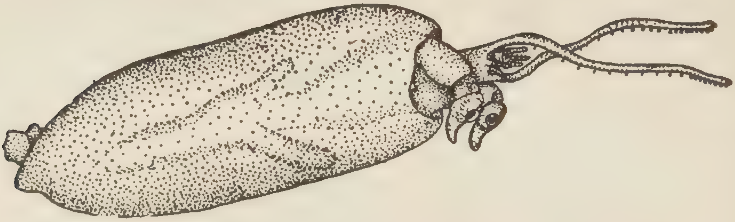


FIG. 104.—Deep-sea squid *Sandalops melancholicus*. South Atlantic, 1000 metres. 5 times natural size.

We know from our own experience that in poor light or complete darkness the sense of touch is able in some measure to replace the sense of sight. This is true also for life in the deep sea, and not a few creatures, particularly some crustaceans and fishes, show considerable extensions of feelers, legs, and fin-rays; fishes also have special thread-like and sometimes branched organs, the so-called "barbels" on the lower jaw, all obviously for increasing the capacity of feeling (Figs. 68, 73). We find this equipment, however, not only in blind fishes and crustaceans of the deep sea, but also in those with quite well-developed eyes. In bathypelagic crabs and prawns the legs and feelers, sometimes enormously lengthened, may also have the function of "floating extensions", which increase the capacity to float by taking advantage of the viscosity of the water (Fig. 105); and the very long extremities of some deep-sea isopods, all living on the floor of the ocean, doubtless facilitate their possessor's crawling over the soft ooze (Fig. 129). Again and again, however, we see how quite close allies of these strikingly equipped species, living under the same conditions in the deep sea, manage without any such adaptations.

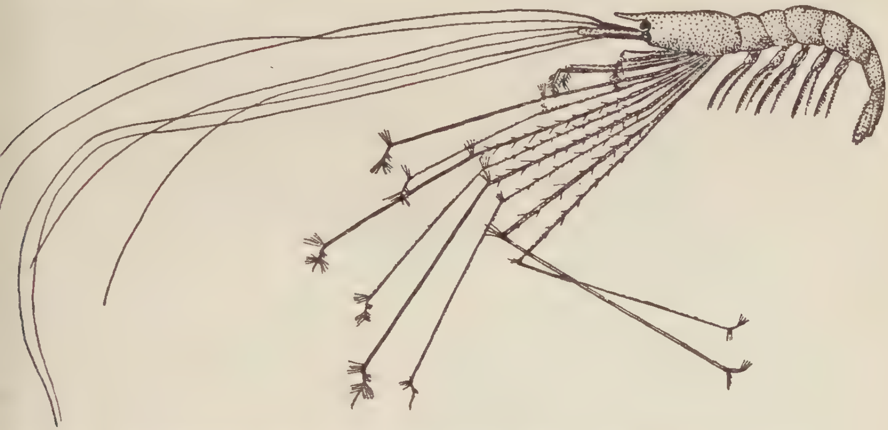


FIG. 105.—A red deep-sea prawn of the genus *Nematocarcinus*. Indian Ocean, 900 metres. Half natural size.

Another means of increasing the capacity to use the sense of touch (in the wider sense) consists in an ample supply of "sense-hairs", little hairs or bristles connected with sensory cells at their end, which when excited furnish their possessor with certain impressions, especially of movements of the water in their immediate neighbourhood. The blind crustaceans of the family of the Eryonidae (Initial letter, Chapter VII), which live entirely in the deep sea, are equipped with a regular fur of such little sense-hairs covering their whole back. Some deep-sea representatives of the brachyuran crabs, *Brachyura oxyrrhyncha*, keep their last pair of legs stretched up above their back when running, and the ends of these legs are covered with sensory hairs like delicate feathers (Fig. 106): no doubt this queer practice also conveys some sort of chemical sense-perception, perhaps a warning of movements of the water caused by the approach of other animals. Presumably we have here a deep-sea adaptation and variation of a habit common among crabs of the shallow water: with the little pincers of their back legs the animals continually hold above their back all sorts of objects, bits of sponge, even stones or bits of seaweed, as a sort of protection. In the deep sea, too, there are species of crab which lift up their last legs, otherwise normal, and even crabs which have pincers powerfully developed in these two legs (Fig. 133); whether they use these, however, to hold up stones or anything else as protection, or whether, as seems very probable in some cases, the legs only serve as a sort of balancing-rod, which might be very useful to them when running over the soft ooze, is uncertain.

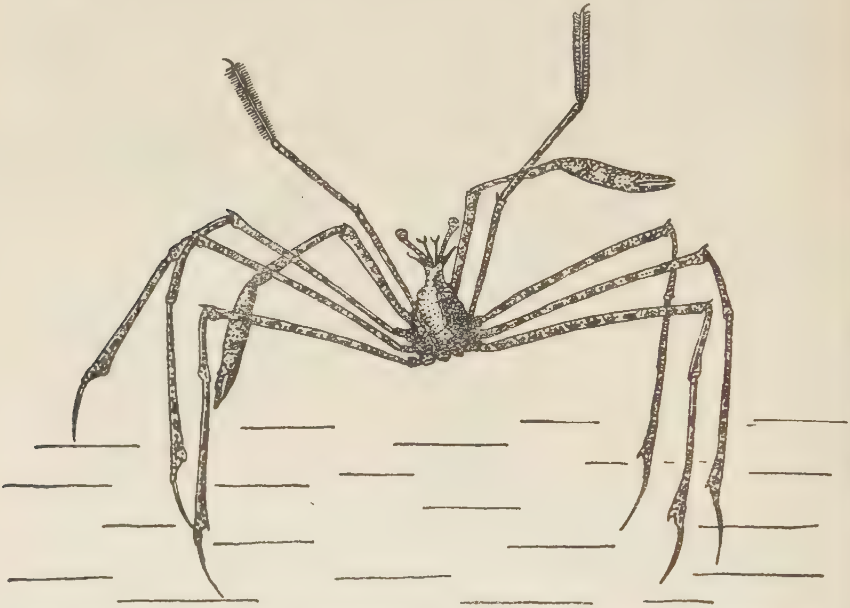


FIG. 106.—The crab *Latreillia phalangium* (Western Pacific, 300 to 1000 metres), seen obliquely from above and behind. Reduced.

The chemical sense that is developed in higher animals mainly as a sense of smell and taste, and in vertebrates on land is confined to the nose and mouth cavity, is spread usually in fishes over the whole, or almost the whole, surface of the body; thus in fishes the nose plays no special part as a sense organ and is hardly ever prominently developed. The only exceptions to this are the deep-sea fishes of the genera *Aceratias* and *Rhynchoceratias* and their closest allies (Fig. 94), which often have a really splendidly developed nose, almost a unique feature in fishes. We have already said, and we shall return to the subject, that these very strange little fishes are the males of the deep-sea anglers, and enter with their much bigger females into those quite incredible marriages for life during which they grow on to the female and are nourished by its blood. Whether their noses, sometimes gigantic, help them to find a mate, or what other purpose they may serve, is unknown.

The little barbels, the fin-rays, feelers, and extremities, often of enormous length, of many deep-sea animals, certainly serve as organs of the chemical sense which in some form makes up for the limitation or loss of vision; their importance in assisting the faculty of touch has already been referred to. The little knobby or flap-like "snout organs" of the bat fishes (Figs. 50, 52) probably belong entirely to the chemical sense. These organs lie in cavities above the snout of these flat benthal fishes, which are allied to the deep-sea devilfishes; the organs can probably be protruded a little from the snout. These snout organs of the bat fishes are homologous with the dorsal tentacles or angling filaments of the deep-sea devilfish; that is to say, like those, they are developed from the metamorphosed first ray of the dorsal fin. Finally, special services of the chemical sense are also probably fulfilled by organs which have no other known functions, and which have only been observed in deep-sea animals, for instance the "back organs" of the rat tails (*Macrurus*), which lie under the surface of the body as cavities in front of the dorsal fin and are provided with a narrow outlet.

Among the most striking and most discussed special features of deep-sea animals is the faculty of self-illumination; its frequency and vigorous development seem specially characteristic of the deep-sea biotope. But luminous marine animals are by no means confined to the deep sea, and on the other hand it must not be assumed that all or even the majority of the species known to be denizens of the deep sea possess the faculty of illumination. We know, for instance, the myriads of minute unicellular organisms, especially flagellates, of the surface waters of the oceans, whose luminescence, especially in a rough sea, causes the familiar phenomenon of phosphorescence in the sea. To this phenomenon belong also the "fire-rollers" of the genus *Pyrosoma* among the tunicates, seen mostly in the surface layers of tropical waters; and in the coastal and surface waters of the Banda Sea are found fishes of the genus *Photoblepharon*, with a very strong light organ under the eyes, capable of being put out, and evidently used for luring animals on which they feed.

The *Valdivia* Expedition established that about one-tenth of the deep-sea fishes caught possessed light organs; bearing in mind that not all luminous deep-sea animals have the faculty of producing luminescence by means of special light organs, the proportion of luminous deep-sea animals may be estimated at 20 per cent.

Luminescence not produced by means of special light organs is found especially in deep-sea animals of low organization, for instance the sessile "feather-polyps", the jellyfishes, the sea gooseberries, the siphonophores, starfishes, and many others. The phosphorescence, too, which Beebe and Barton observed on parts of the bodies of deep-sea fishes is quite obviously not produced by light organs, but probably by a mucus which becomes luminescent on emerging from the glands that produce it and then spreads over the skin of those fishes.

The light organs of the deep-sea fishes vary in size and form. Their source in all cases is functionally metamorphosed skin glands, and they are found in all stages of development from simple gland cells to complicated and powerful gland organs, with focusing lenses and reflectors for the light they produce. It is particularly from these light organs, sometimes astonishingly like eyes, that the strong lights come which are found, for instance, in the stomiatoids, the lantern fishes, or *Aethroprora effulgens* with its "nose lantern". The organs are cup-shaped depressions beneath the skin, which at that spot is transparent; they are lined with opaque surfaces of black or red pigment; within them are masses of shining interwoven fibres which have the effect of a reflector; over them is a layer of cells which produce the light, and this is collected by a lens. In front of the lens there may also be a diaphragm brought into play by muscles, or shining fibres working as a reflector, or thin layers of colour cells which give a particular colour to the light sent out. Many luminous animals are able to turn and move their light organs by means of special muscles, and the light organs are always provided with special nerves. Clearly, most of the luminous animals can turn their lights on and off at will; this was confirmed by Dr Beebe's observations; it is done by nerves or hormones. It has been established in the case of fishes that adrenalin similarly induces activity of the light organs. Adrenalin is a hormone widely found among vertebrates; in human beings it is produced by the adrenal glands.

The luminescence itself is a highly complicated chemical process; it is known as "chemoluminescence": "cold light" is produced, that is, light without heat, a problem which has long exercised the human inventive spirit and has only recently been brought near to a solution. In the bioluminescence of luminous animals a phosphoric compound, "luciferin", is oxidized into "oxyluciferin", a process, however, which takes place only in the presence of a particular ferment or enzyme, "luciferase". Often, however, these materials are not all formed directly by the cells of the luminous body in which the process referred to takes place, but by luminous bacteria living between or in these cells. We have here a case of close association, known as symbiosis, between two very different creatures, from which each partner profits. Sometimes, as in the present case, it takes the form of "intracellular symbiosis", so called because one participant in the association lives within particular cells of the body of the other. The advantage to the fishes consists in the faculty of luminescence, of biological utility to them, and the advantage to the bacteria consists in the protected existence in favourable conditions provided for them. Particularly in the deep sea, however, most of the luminous animals produce their light without the assistance of bacteria, and this is true above all of the stomiatoids, whose light organs, as we have said, resemble eyes; of the lantern fishes, and of most of the luminous cephalopods. Among the deep-sea fishes the anglers or devilfishes live in symbiosis with luminous bacteria, which settle in the end organs of the head lanterns of these fishes and produce their light.

The significance of light production in luminescent deep-sea animals with that faculty has four main aspects. It serves for luring prey; it certainly serves in many cases for frightening off enemies, as, for example, in the clouds of light created by some prawns and cephalopods, or the screening lights of the deep-sea lantern fishes. A third very important function served by the luminescence of deep-sea animals is that of enabling the sexes to find each other, and also enabling species that move in schools to keep together. Particular arrangements and colours, of course, of the light are characteristic of the different species; in some species the sexes show characteristic differences in the detail of their lights. Finally, there is a fourth purpose served by light organs, to light up the field of vision and the objects to be seen; undoubtedly this is a minor function, but it exists. It is obviously for some such purpose that the light organs of so many deep-sea animals are situated so close to the eyes.

Peculiarities which must have some connexion with the natural conditions in the deep sea with regard to light are shown by the colouring of deep-sea animals. Among the animals of the surface waters a bluish or silvery sheen predominates, with a brighter upper side and a darker under side; in deeper water the colour progressively darkens, but at about 500 metres' depth there are many cases of a bright red colouring, while in still deeper water, and especially in the abyss, only quite dark-coloured animals—brown and still more frequently black—are found. Exceptions are the swimming crustaceans (schizopods) and prawns, which retain their bright red colour down to the greatest depths; also the quite colourless, translucent, or flesh-coloured marine animals, frequently met with in the upper water among the smaller forms of the plankton, and in the deep sea among the smaller squids of the bathypelagic zone (Fig. 64). Less frequent exceptions exist among fishes, especially benthal species. Silvery or metallic colours, very general among the marine animals of the sunlit upper layers of the water, are rare in the deep sea; we found them among the ribbon fishes of the genera *Regalecus* and *Stylophorus* (Figs. 85, 121) and the giant-tails (genus *Giganturus*, Fig. 137). The biological importance of the peculiarities of colouring of deep-sea animals is mainly unexplained. It has been pointed out that at the limit of the penetration of light, at a depth of about 500 metres, where red-coloured animals prefer to live, red is the complementary colour of the greenish-blue to violet irradiation at that depth, so that the red-coloured animals must be almost invisible; and similarly the colours of other deep-sea animals may probably be best explained as protective camouflage.

The scarcity of food in the deep-sea biotope makes it necessary for the bathypelagic animals to be able to overcome every sort of prey they meet with, whatever its size, and we have made acquaintance with the great teeth, the enormous jaws, and the uncannily extensible stomachs of so many deep-sea fishes as adaptations of vital importance to their possessors. We have seen that in this the small *Chiasmodon* perches (Fig. 88) are probably the most remarkable performers, but many deep-sea devilfishes, gulpers, and giant-tails, come close behind them in the capacity of their stomach. Catches and observations have shown again and again that these predatory animals of the deep sea can swallow prey much bigger than themselves. It is difficult for us to visualize the actual process of swallowing, for the jawbones must be capable of stretching in every direction to pass down such immense mouthfuls, so that we must assume the existence of some sort of elastic bands between the bones of the jaw. These deep-sea animals are alone in the whole realm of the vertebrates in their faculty of performing these feats of swallowing, and no less unique is their incredible capacity of stretching their stomach. The details of the mechanism by means of which these feats are performed are still unknown; but clearly the formation and reinforcement of the jaws of these deep-sea fishes must be extraordinarily specialized.

Among the higher vertebrates, especially the mammals, including the human species, the upper jaw with its maxillary hinge is firmly attached to the cranium (Fig. 107); in fishes the jaw mechanism is only attached to the fore end of the upper jaw, with the after part propped against it, or hung on it by a special attachment, the suspensorium. The suspensorium is of various forms and consists of many different elements of bone, of which the most important is the hyomandibular or tongue-bone. The bony fishes have special muscles only for closing the jaw, not for opening it; it is opened by the tongue-bone (which lies behind and below the lower jaw in the floor of the mouth) being drawn back and dropped by special muscular contraction from the shoulder girdle. This movement is carried through the floor of the mouth to the lower jaw and opens it. The skull is bound fairly strongly to the backbone, so that it has scarcely any freedom of movement up and down in relation to the backbone.

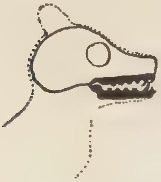


FIG. 107.—Plan of attachment of the jaw mechanism in the skull of a mammal. Black: upper and lower jaws. The dotted line shows the outline of the body.

These relations are shown by our diagrams (Figs. 108, 109); a knowledge of them is necessary in order to understand what follows.

In the fact that the jaw mechanism of the bony fishes is suspended from the cranium in the manner shown, and that accordingly the jaw-hinge lies apart from the cranium, lies the sole possibility of expanding the jaw's space for seizing, holding, and biting by means of a backward extension of the jaw. This possibility would be open in itself to all bony fishes, but actually exists, strangely enough, only among deep-sea fishes. All higher vertebrates, whose upper jaw and jaw-hinge are firmly attached to the cranium, can in any case only extend their jaw forwards as they develop, as, for instance, among the crocodiles or the canine beasts of prey.

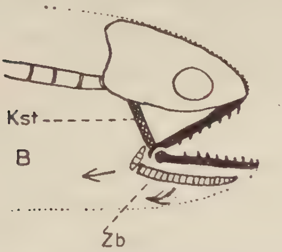


FIG. 108.—Plan of the normal attachment of the jaw mechanism in the skull of a bony fish. The fore end of the backbone is indicated. Black: upper and lower jaws. Kst: hyomandibular. Zb: tongue-bone; from it start, in the direction indicated by the arrows, muscles which open the lower jaw. Dotted line: outline of body.

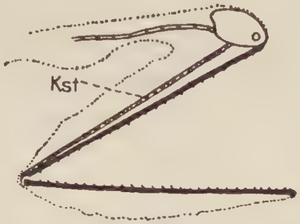


FIG. 109.—Plan of the attachment of the jaw mechanism in the skull of the pelican eel (*Eurypharynx*). The fore end of the backbone is indicated. Black: upper and lower jaws. Kst: hyomandibular. Dotted line: outline of body.

With the backward-directed extension of the suspensorium and jaw are associated, in the deep-sea fishes in question, some very varied and always highly interesting specializations, all of which are concerned with adaptations to enable even very big animals to be seized. Almost the simplest method has been adopted by the gulper (genus *Eurypharynx*, Figs. 80, 109), and with almost sensational success. Its suspensorium is extended backwards and down incredibly far; the actual upper jaw joins in this extension and lies on the suspensorium. In this enormous extension of the jaws the hyoid bone becomes dissociated from the lower jaw and in any case is no longer in the floor of the mouth. Through this, however, the gulper loses the capacity of actively opening its jaws, for the bony fishes, as we have said, use their hyoid bone for this purpose; probably the gulper's mouth opens of its own accord, first through the weight of the lower jaw, and then through the resistance of the water, so long as it does not deliberately keep it shut. The muscles for closing the mouth in *Eurypharynx* are very thin and weak, and this robs it of the faculty of seizing and holding its great morsels of prey with its needle-like jaws. What the gulper has achieved by its specialization is a great roomy bag, formed by its mouth with the very wide folded skin on all sides of it; it can extend this bag backwards as well by spreading its jaws widely, so that when seen from above it looks like a cocked hat (Initial letter, Chapter I).

These gulpers can only secure their food by the process of stuffing in whatever comes along: they are not hunters. Their whole form, the minuteness of their fins, their immense mouth, in proportion to which the rest of their body is but a feeble appendage, show that they are poor swimmers and therefore must live as lurkers, waiting for chance victims. Probably they lure them by means of a light organ at the end of their body. If a suitable victim comes near enough, they pounce on it and stuff it down the enormous bag formed by their huge jaws with the folded and extensible skin surrounding them; then they close the jaws and gulp down the victim into their stomach.

The stomiatoids or dragon fishes have similar suspensoria and jaws, though not of such huge dimensions; the jaws are considerably extended backwards. The jaw mechanism and the tongue-bone, however, remain in these fishes in entirely normal association with one another and with the rest of the body—apart from an exception to be referred to later. But in the case of the dragon fishes this specialization is not connected so much with the increased capacity of the mouth, which, it is true, is considerable, as with an increase in the jaws' range of snapping and biting; this is shown by the very strong muscles that close the jaws and especially by the gigantic canines of these fishes, which in some species, as in the viper fish already mentioned (genus *Chauliodus*, Fig. 10), attain really incredible length. The biological importance of these huge bent canine teeth consists in their ability to hold for any length of time a victim which they have once in their grip and hanging from them, without the necessity of a continued pressure of jaws and dentition. Something more is needed, however, to make it possible to make use of this faculty, that is to say, to open the mouth enormously wide. To this end the stomiatoids have developed a further remarkable specialization: they are able to use their very strong neck muscles to throw their head, as it were, back into their neck; in this way, as the diagram (Fig. 110) shows, they bring the suspensorium with

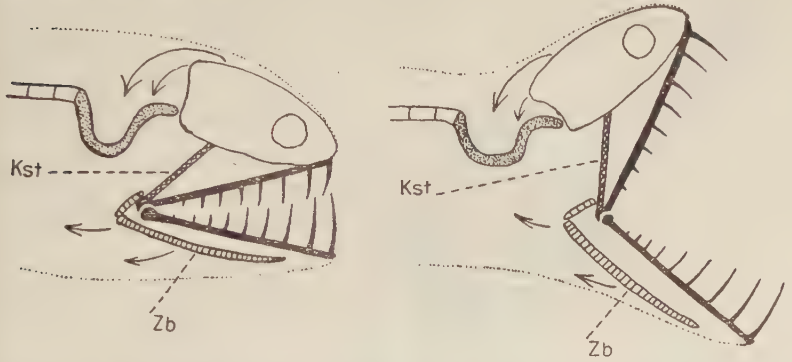


FIG. 110.—Combined plan of the attachment and functioning of the jaw mechanism in highly specialized stomiatoid fishes. The fore end of the backbone remains cartilaginous (dotted line), and is S-shaped in some species of *Eustomias*. Black: upper and lower jaws. Kst: hyomandibular. Zb: tongue bone. Muscles working in the direction of the arrows pull the skull upwards and backwards and the tongue-bone backwards when the mouth is opened. Dotted line: outline of body. Right, the same, but the jaw opened by muscles working in the direction of the arrows.

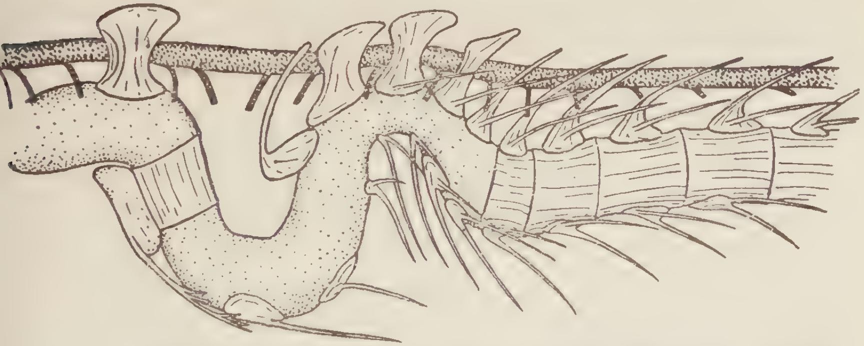


FIG. 111.—Fore-end of the backbone of the deep-sea *Eustomias brevibarbatus* (Caribbean Sea). Thick dotted line: spinal cord; lightly dotted section, the boneless part of the backbone. 8 times natural size.

the upper jaw forward and by simultaneously dropping the lower jaw they produce an exceptionally wide opening of the mouth.

Since the prey of the stomiatoids may be as big as themselves or bigger, it is easy to imagine that in its desperate efforts to get free the victim will wildly and violently shake its captor; these efforts will put a very considerable strain on the solidity not only of the teeth but of the connexion between the head and torso, the skull and backbone of the beast of prey. For this, too, the stomiatoids have developed a special adaptation: the fore end of their spine is not bony but cartilaginous, and sometimes, as in the genus *Eustomias* (Fig. 111), forms an S-shaped curve when viewed from the side. This offers an elastic and in special cases even a well-sprung basis for withstanding the heavy strain on the captor's head in its effort, as described, to secure its prey.

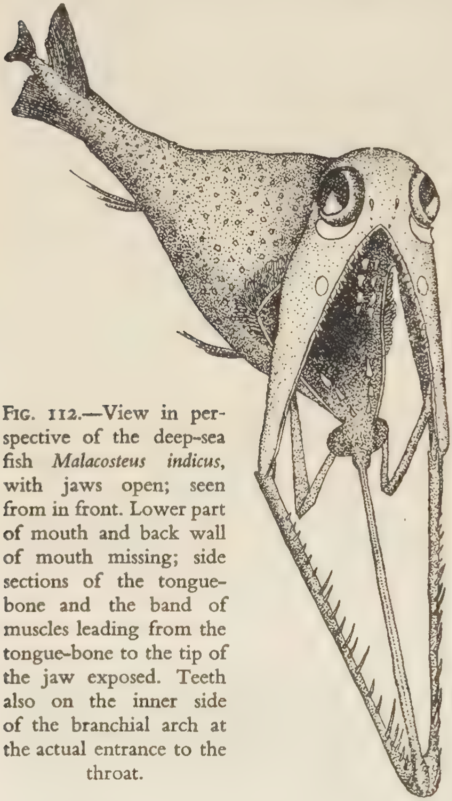


FIG. 112.—View in perspective of the deep-sea fish *Malacosteus indicus*, with jaws open; seen from in front. Lower part of mouth and back wall of mouth missing; side sections of the tongue-bone and the band of muscles leading from the tongue-bone to the tip of the jaw exposed. Teeth also on the inner side of the branchial arch at the actual entrance to the throat.

Finally, the most highly developed stomiatoids, those of the family of Malacosteidae (especially the genus *Malacosteus* (Figs. 112-118), have availed themselves with really almost inconceivable success of the adaptations of the other stomiatoids already described. The *Malacosteus* fishes have lost the whole of the lower and hinder skin-limitation of their mouth-cavity; they have no floor and no back wall of the mouth; only narrow clappers and clasps without any skin connexion between them are furnished by the suspensorium with the upper jaw and the lower jaw attached to it, and the mouth cavity remains entirely open behind and below. The jaw mechanism is deprived in this way of almost all connexion with the rest of the body—with the exception of the cranium, to which it adheres—and now when *Malacosteus* "throws its head back into its neck" like the other stomiatoids with the aid of its strong neck muscles, and so pushes the whole jaw mechanism forward, its throat and neck are wide open behind the mouth, as the back of the mouth is completely open. The bones of the gill cover, which in other bony fishes play an important part in the breathing, are incorporated in *Malacosteus* in the suspensorium, so that they only cover the gill when the suspensorium is at rest; if the whole jaw mechanism is pushed forward, in the way described, by the drawing back of the upper part of the head, the gills, like the neck and the entrance to the throat, are entirely free.

The tongue-bone is of critical importance in the use made by *Malacosteus* of this extraordinary peculiarity. The middle portion of the tongue-bone is joined to the lower ends of the bony gill-arches, while the ends of its side branches are movably attached to the suspensorium, as in most bony fishes; since the floor and the back wall of the mouth are absent, the side branches of the tongue-bone form completely free, long bands, folded crosswise when at rest, between the side flaps of the head (formed by suspensorium and upper jaw) and the unpaired middle section of the tongue-bone joined to the lower ends of the gill arch. From this an extremely extensible muscle, enclosed in a compartment of the skin, runs freely to the tip of the lower jaw. A special contraction of the muscle enables the animal to drop the middle section of its tongue-bone from the position of rest and then to open its mouth by means of the band of muscle leading to the tip of the lower jaw; then, with the aid of its very strong neck muscles, it "throws its head back into its neck", and in the further course of this movement it brings the opened lower jaw a considerable distance forward, until finally the lower jaw is suddenly brought short by the band of muscles

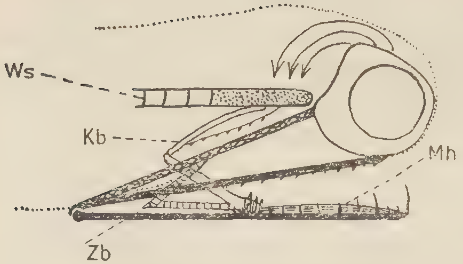


FIG. 113.—Plan of the structure and attachment of the jaw mechanism in the skull of the deep-sea fish *Malacosteus indicus;* head and jaw at rest. Dotted line, outline of body. Black: upper and lower jaws. Hatching: hyomandibular. Ws: backbone with cartilaginous fore-end (dotted). Kb: branchial arch. Zb: Tongue-bone. Mb: band-like muscle running from the central portion of the tongue bone to the tip of the lower jaw.

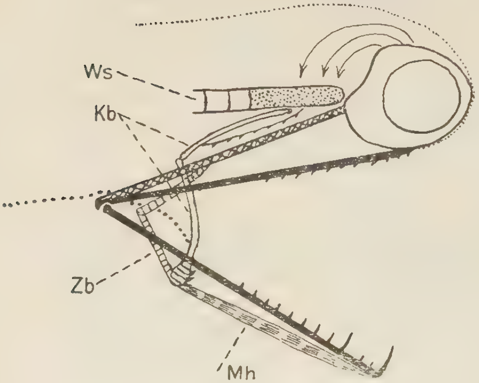


FIG. 114.—First stage of the opening of the jaw: the middle portion of the tongue-bone is lowered by muscles (not shown), and with the aid of the muscle Mh opens the lower jaw.

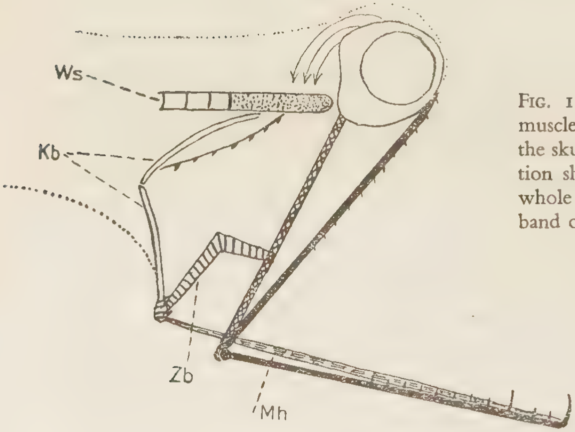


FIG. 115.—Opening of the jaw: the muscles leading from the upper side of the skull to the backbone, in the direction shown by the arrows, bring the whole jaw mechanism forward as the band of muscles Mh gradually relaxes.

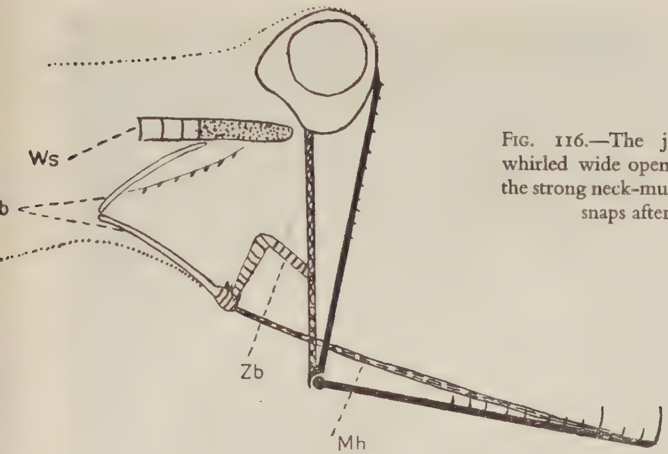


FIG. 116.—The jaw mechanism is whirled wide open by the pulling of the strong neck-muscles; the lower jaw snaps after the prey.

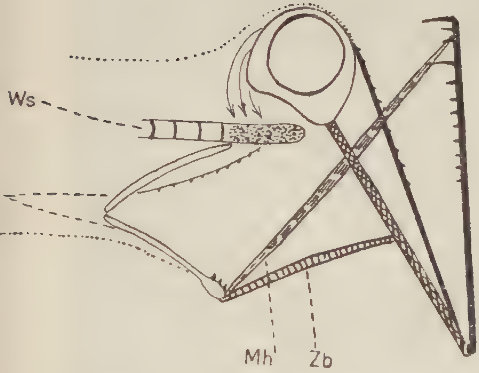


FIG. 117.—Straight from the preceding position the lower jaw is snapped to with the prey (not shown) by the band of muscles Mh.

reaching from the tongue-bone to the tip of the lower jaw. This succession of movements no doubt takes place with the utmost speed, enabling *Malacosteus* to snap suddenly and unexpectedly with its outstretched lower jaw at an approaching animal, and at the same time, by immediately snapping shut its lower jaw, to carry its prey down its throat (Figs. 113-118).

Now it is possible to understand why the *Malacosteus* fishes, unlike the other stomiatoids, possess large canines only in the lower jaw, not in the upper jaw as well; for they strike at their victims

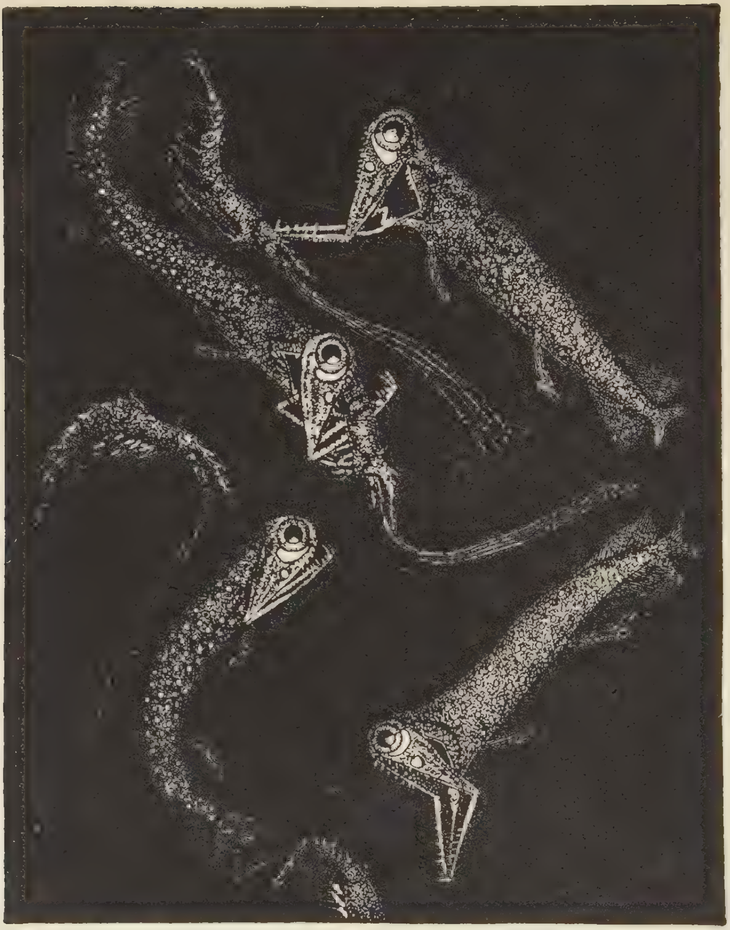


FIG. 118.—The soft-rayed fish *Malacosteus indicus* hunting prawns. 1000 to 3000 metres. Half natural size.

only with the lower jaw. But especially it will be clear now what is the biological importance of the complete absence of skin in the floor and back part of the mouth; for otherwise the resistance of the water would be much too great for the sudden lightning movement of the hurling forward of the jaw to be possible. Thus the *Malacosteus* fishes depend entirely on sizable prey, smaller creatures would be able to escape behind and below from the mouth. It is true that the muscular band between the tongue-bone and the tip of the lower jaw and the two bands of the side branches of the tongue-bone passing freely to the suspensorium imply a certain narrowing for such a backward exit from the mouth; for the rest, so far as its reach permits, the jaws of *Malacosteus* can be splayed wide apart in seizing large prey.

The extraordinary method used by *Malacosteus* in securing its food, as described, is entirely unique and makes this deep-sea denizen one of the most highly specialized of the fishes and of the vertebrates in general. In the whole animal kingdom there is, strictly speaking, only one single parallel to the behaviour of *Malacosteus*, namely the method of acquiring food adopted by the larvae of dragon-flies, which strike at their prey with their underlip, formed into the so-called "seizing mask". The favourite food of *Malacosteus*, found in the deep water of all oceans, between 1000 and 4000 metres, seems to be the deep-sea lantern fish (genus *Myctophum*), as these fishes have been found again and again as the contents of its stomach.

Looking back on the adaptations described in gulpers, stomiatoids, and *Malacosteus* fishes, we find in all of them a quite similar principle of specialization, the backward lengthening of the suspensorium and the jaws, as the point of departure for very different adaptations, in close connexion with and in similar relation to the great scarcity of food in the deep sea, in so far as they enable these predatory fishes to gain possession of animals much larger than themselves. And the result of these very varied combinations of the strangest individual adaptations, based on the same principle and aimed at the same end, was the adoption in the cases of *Eurypharynx* and *Malacosteus* of such entirely unique forms of acquisition of food as make them in these respects the most strangely developed members of their whole family, with only one or two parallels in the whole animal kingdom.

Another peculiarity in the formation of head and mouth in connexion with the acquisition of food is shown in the deep-sea angler fishes of the genera *Lasiognathus*, *Thaumatichthys*, and *Amacradon* (Figs. 119, 120, 124, D, E.). We have already mentioned the first of these as the possessor of a long jointed head-lantern, actually provided at the end of it with a hook like a fishing hook; it may be, however, that this very genus, and the two other genera, which have a quite short lantern filament far forward on the head, are unlike almost all other deep-sea angler fishes in not living on relatively large prey but on small plankton animals such as arrow worms and schizopods, which are found in shoals at considerable depths. In these fishes the outer bones of the upper jaw, which are furnished with long brush-formed teeth pointing outwards, are connected

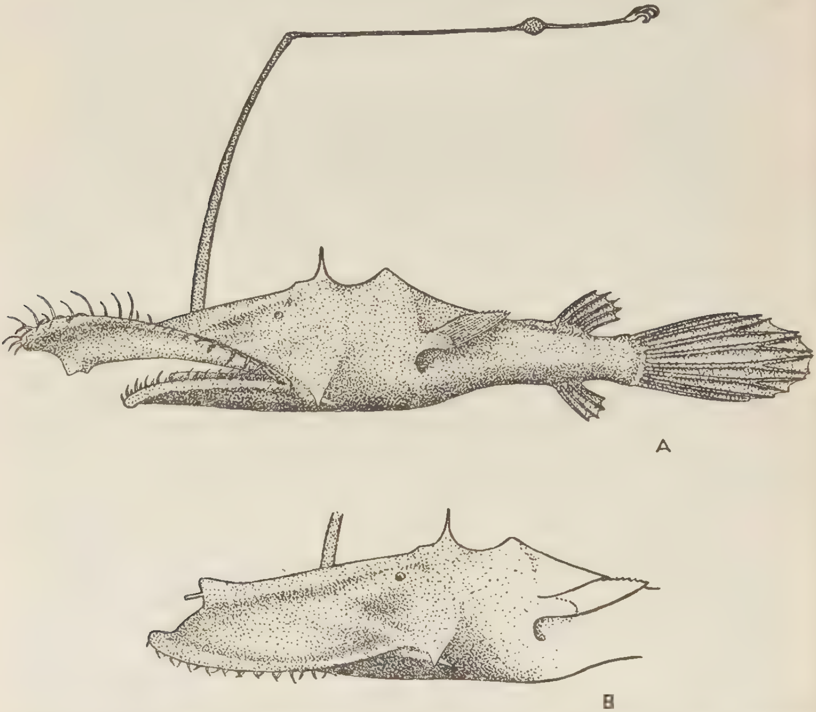


Fig. 119.—Basket-jawed deep-sea angler. Caribbean Sea, 4000 metres. A: with the side rims of its upper jaw raised and its mouth open. B: with the rims of its upper jaw turned down and the mouth shut. $\frac{1}{3}$ natural size.

with the head only by a wide pliable skin, and in front not connected with each other at all; they come back, however, upwards above the head, but are also turned back inwards below and then form, with the teeth now turned inwards, a closed basket or net. The whole probably forms a sieving or filtering mechanism for sieving small though not actually minute plankton organisms from the water; functionally the mechanism would in that case be comparable with the gigantic mouth of the whalebone whales, which use their closely set whalebone beards as a sort of filtering and sieving mechanism.

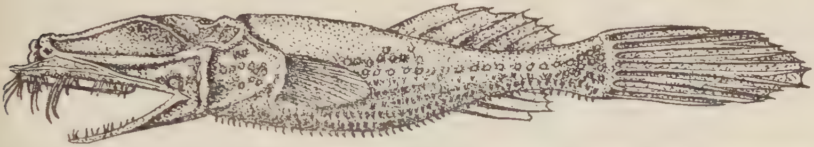


FIG. 120.—A basket-mouthed fish (*Thaumatichthys pagidostomus*) Gelebes Sea, 1300 metres. Natural size.

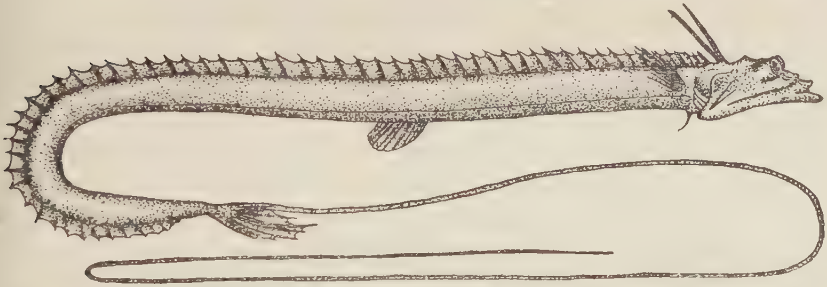


FIG. 121.—The filament-bearing fish (*Stylophorus paradoxus*) in the depths of the Atlantic, has telescopic eyes. It grows to a length of a yard.

Let us finally mention here the strange and rare filament-bearing fish *Stylophorus* (Fig. 121), of the order of ribbonfishes; with its narrow mouth it must obviously depend on small prey, securing them by a sudden thrust and snap of its jaws. This trick is known by many other species of fish, not living in the deep sea; but the performance of *Stylophorus* is unique in that it "throws its head back into its neck" like the stomiatoids. The mechanism which then thrusts the fish's snout far forward works in this case too on the basis of the backward extension of the suspensorium and the lower jaw; but its functioning remains unexplained and obscure because the upper jaw of *Stylophorus* has no connexion with the cranium or the lower jaw.

The sparseness of settlement especially of the larger animals of the deep sea in their inconceivably vast habitat is connected with the difficulty which the sexes have in finding each other. We have said that luminous creatures of those abysses may attract each other by means of the light they produce, and may recognize each other by the characteristic arrangement of their lights as members of the same species; in general, we have no knowledge of the way other animals with no light organs master this problem. The problem is not a great one for species that keep together in schools or shoals, and, perhaps, not too serious for active swimmers and hunters that rove restlessly through the water, and so may well meet other members of their species from time to time. The prospect of that, however, is greatly reduced for the more lethargic solitary animals that depend on lurking for their prey—characteristics which must add considerably to the difficulties of most of the deep-sea devilfishes (*Ceratioidea*, Figs. 89–93) in mutual recognition by the sexes. These devilfishes or anglers have evolved a quite incredible expedient for escape from this difficulty, an expedient unique in the whole class of vertebrates. Long ago it was found astonishing that only females of these fishes were caught, until at last it was discovered that apparent parasites occasionally found on the bodies of the females were the males of the species (Figs. 94, 122). Thus in this case the male and female, not to lose each other in the infinity of their habitat, enter into the strangest of all compulsory lifetime unions. The males, probably not in their earliest youth, grip with their jaws a female of their species at any spot in its body, in its side, on its head, on the gill cover, or wherever else it comes into contact with its female; we have already described how then the male's jaws and tongue grow into tissues of the female and how the blood circulation of the two is united and the males share the nourishment of the body fluids of the females. Some of the male's organs, especially those of nutrition, now degenerate, as it no longer has any use for them; others, such as the glands of reproduction, are powerfully developed; in these species it seems very probable that the male's sexual organs do not mature until it has succeeded in adhering to a female. What happens to males that do not secure attachment to females in this way, and what means of reproduction have those females which are not found by a male? We do not know. Females of these species without males attached to them have been much more frequently found than those with dwarf males on them, and males swimming alone have been found. In the past the males —fat little things only 1 to 2 inches long—were distinguished in

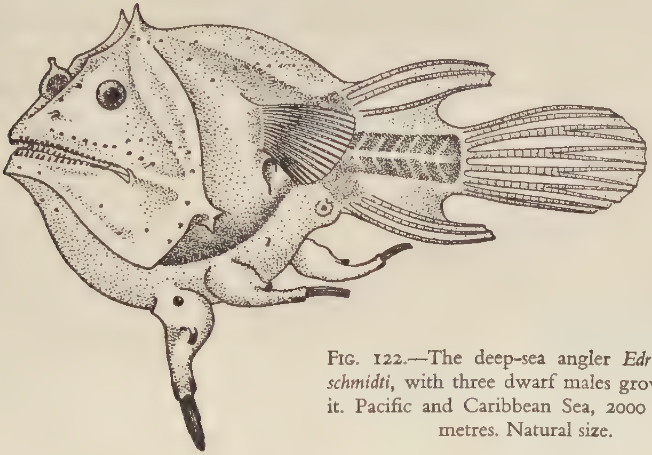


FIG. 122.—The deep-sea angler *Edriolychnus schmidti*, with three dwarf males growing on it. Pacific and Caribbean Sea, 2000 to 3000 metres. Natural size.

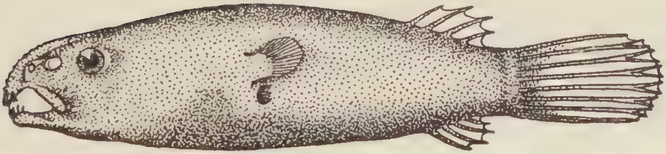


FIG. 123.—"Pincerfish", free swimming male (*Rhynchoceratias ogcorrhynchus*) of a deep-sea angler. North Atlantic, 2500 to 4000 metres. Double natural size.

error, owing to their great difference from the female, as a separate family, the Aceratiidae; they differ from the Ceratioidea, which we now know to be their females, in having no head lantern, in having a very large and strikingly developed nose, and usually in having remarkable pincer-jaws with a few strong teeth (Figs. 94, 123).

The males are more active than the much bigger but lethargic females, and are better swimmers, so that they are evidently able to pursue and overtake the females. In this pursuit they are probably well served by their specialized nasal organs, which are the seat of a specific chemical sense. They then fasten themselves to the female

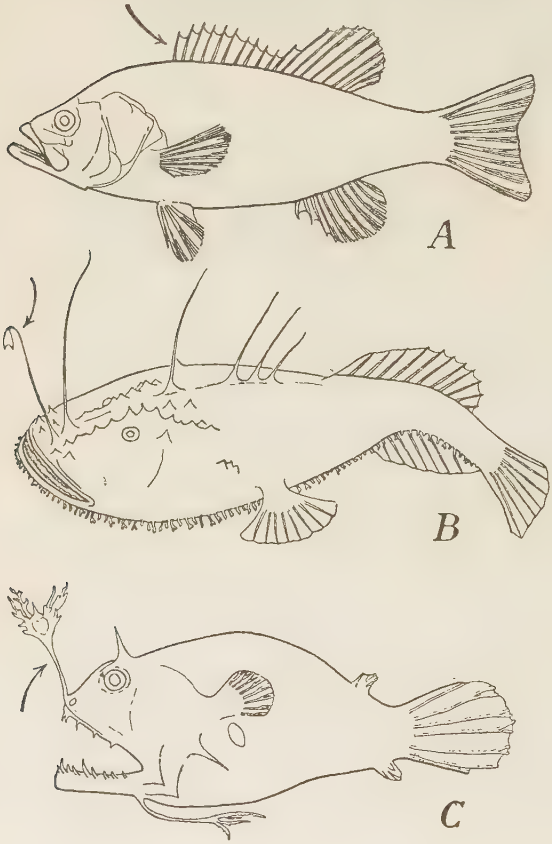


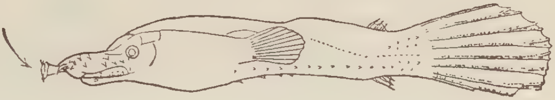
Fig. 124. — Developmental changes in the first ray of the dorsal fin in fishes.

A: Normal position and development in the dorsal fin of the American black perch (*Micropterus salmoides*).

B: Fore ray of the dorsal fin, separated and transferred to the head. Devilfish (*Lophius piscatorius*).

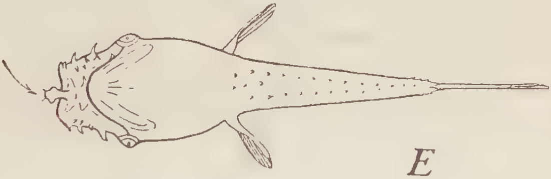
C: First ray of dorsal fin changed into the "head lantern" in a deep-sea angler (*Linophryne brevibarbis*).

with their jaws. Whether this leads in every case to the growth of the two into each other, or whether after a time the males can regain their independent existence in some cases, seems an open question in view of the great number of "unwedded" females that are found. It is assumed that in other allied groups of the deep-sea anglers the males preserve their independence and never enter into the compulsory union here described; often enough, however, they have the very distinctive pincer jaws, so that it may be conjectured that they attach themselves to their female at least for a time. The compulsory and permanent union, in which the male becomes a complete parasite on the female, may perhaps be regarded



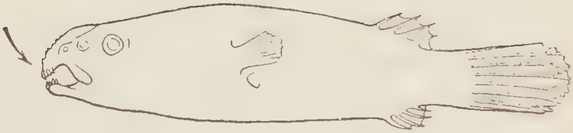
D

D: First ray of dorsal fin converted into a short "snout-lantern" rising from the lower edge of the upper lip, in a deep-sea devilfish (*Amacrodon binghami*)



E

E: The same fish as in D, from below.



F

F: First ray of dorsal fin converted into the "upper denticle-bearer" in a male deep-sea devilfish (*Rhynchoceratias ogcorrhynchus*).

as possible, though not always inevitable, at least in some groups of the deep-sea devilfishes. It is an extreme specialization nowhere else even approached in the whole order of vertebrates. In the whole animal kingdom there are only a few parallel cases of males dependent as parasites on the females; one is the famous green "star-worm" *Bonellia*, of the Mediterranean coasts, and another case is that of some species, again not deep-sea dwellers, belonging to the barnacles (order Cirripedia).

The deep-sea anglers show yet another special development: the first ray of the dorsal fin, often converted in the bony fishes to the most varied and sometimes the remotest uses, is converted in the female anglers into a lantern filament and in the males, which have no head lantern, into the bearer of the striking incisors of the upper jaw, which is situated in these animals in front of the actual upper jawbone and so causes the strange formation of the pincer jaws often observed in these animals. That these two formations, so different from each other, the female's head lantern and the bearer of the upper incisors in many males, are "homologous", that is to say, of similar origin, both being due to conversions of the first ray of the dorsal fin, is proved by a particular anatomical discovery. The so-called fin-ray basal bone, a thin, bony clasp uniting each ray of the dorsal fin with the neural spines, is present for both of the formations in question, and so shows the similar origin of the female's lantern-filament and the male's upper denticle bearer. The fin-ray basal bone for the upper denticle bearer (this latter being the modified first fin-ray of the dorsal fin) appears to have a special function; by pushing forward the corresponding denticular bone, this being attached to the skull, the forward toothed part of the denticular is pressed down, so making possible a strong closure of the jaws (Fig. 134).

But the conversion of the first dorsal-fin ray is not carried to the point described in all the males of the deep-sea anglers. In some males—it is not definitely known in all cases to which females they belong—the conversion has proceeded only about half-way. In these the modified first dorsal-fin ray has not yet become the bearer of the upper denticles of a pincer-like dentition, but has remained as a functionless collection of small teeth, serving no particular purpose, above the normally developed upper jaw. This phenomenon is of great importance to the theory of development, and we shall return to it (Fig. 136).

To sum up, we find also in the case of the deep-sea angler fishes that the biotope of the deep sea has favoured such unique and highly developed adaptations as are not met with in any other inhabited regions, in correspondence with the quite special conditions of existence in the deep sea.

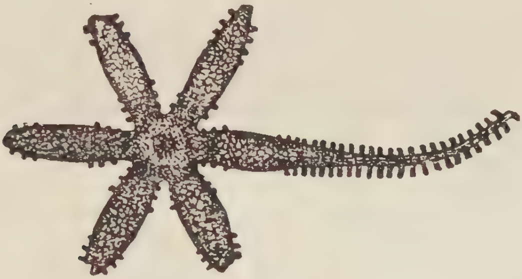
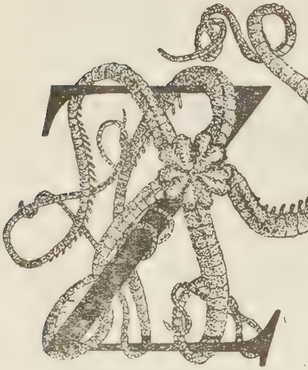


FIG. 125.—The starfish *Freyella sexradiata*, of primitive six-ray structure. North Atlantic, 4700 metres.

CHAPTER XI

DISTRIBUTION AND ORIGIN OF THE DEEP-SEA FAUNA

The zones of distribution in the deep sea – Worldwide or sporadic appearance – Limitations of spread – The ecographical and the genetic question of the origin of the deep-sea fauna – "Living fossils" – A tassel-finned fish, supposed to have been extinct for 75 million years, found alive – The conditions for the settlement of the deep sea – The factors in evolution and their combined effect



Zones of habitation in the deep sea cannot be precisely defined. The first thing needed is to define the upper limit of the animal world of the deep sea, and this, too, cannot be done with precision; but we saw above that the upper limit may be taken as between 200 and 400 metres below the surface. For this is the zone of the most pronounced and the most general change from the animal forms belonging to the upper water to those found in the depths of the oceans. Lower down there is a clear limit between the movement of the upper and lower deep-sea faunae; it may be set at 800 to 1100 metres below the surface. The deep-sea animals found above the 1100 metre limit are called the upper bathypelagic fauna so far as they are swimming creatures, and the animal world living on the floor of the continental slopes is called the archibenthal fauna. Lower still, down to the deepest depths, lives the lower bathypelagic animal world or the pelagic abyssal fauna, and on the floor of the oceans the benthal abyssal fauna.

The differences mentioned in the vertical distribution of deep-sea animals are determined ecologically, that is to say, by their environment. The principal part in this is played by what are called the hydrographical factors, the conditions in regard to light, and to the temperature, salinity, viscosity, and oxygen and carbon dioxide content, of the sea-water. It was shown in an earlier chapter that some species prefer the deep water because of its low temperature, and others live in the depths of the ocean because they can only exist in the relatively still water there. To the examples already given in the latter regard may be added the remarkably formed sunfishes (Figs. 126, 127), belonging to a small family of the order of the Plectognathi ("jointed jaws"). These unwieldy, immobile, lethargic monsters (the largest species, *Mola mola*, attains a length of 6 feet and a weight of half a ton) are to be found on the surface in all oceans, not so very rarely, when the sea is quite calm. There they sun themselves, and with a little caution they can be caught. If the weather changes and the water is no longer calm they go back into the deep sea, where their very different but equally strange young are to be found. There they feed on relatively small prey, and seem especially to prefer the *Leptocephalus* larvae of the various species of eel. Their preference for the deep sea certainly has nothing to do with any fragility: on the contrary, their tissues are as tough as leather. Their preference is certainly due to their extraordinary lethargy and helplessness, which make any roughness of the upper water unsafe for them.

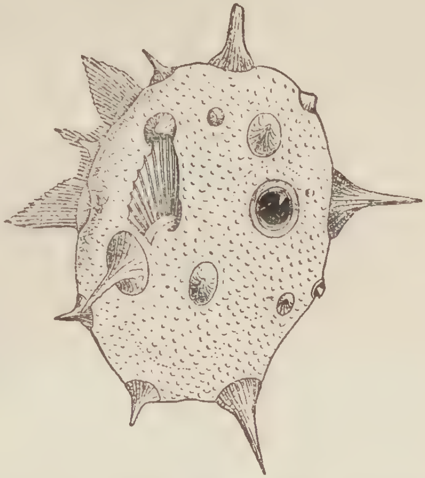


FIG. 126.—Young of the tailed sunfish (*Masturus lanceolatus*) from the deep sea of the Pacific, 13 millimetres (half an inch) long.

A further factor that leads animals to prefer the deeper water may be a dislike of light. Species that definitely need light will not be found in deep water, but a preference for dusk or darkness leads not a few marine animals to live in the deep sea, rising at night, if undeterred by any other circumstance, to the upper water with their more ample food supply. Examples of this habit among the fishes are offered by the slender *Idiacanthus* species (Stomiatoidea), mentioned earlier on account of the tubular eyes of their larvae and the surprising changes in the eyes; and very many species of the lantern fishes (genus *Myctophum*, Fig. 11).

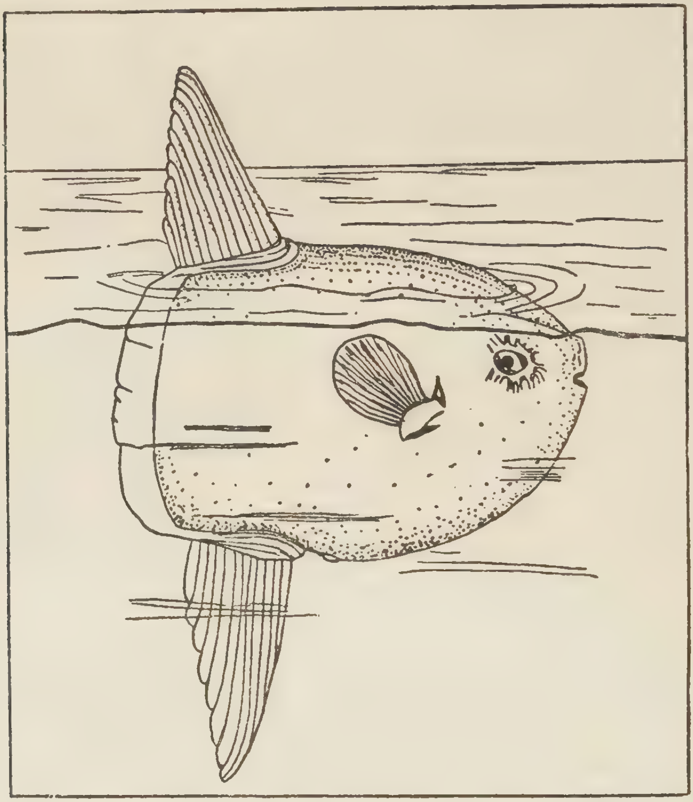


FIG. 127.—The great sunfish (*Mola mola*).

The salinity of the water evidently has scarcely any influence on the distribution of marine animals, especially as it diverges very little from the general proportion of 3·5 per cent. Any excess or shortage is found only in almost enclosed basins of the sea such as the shallow Baltic, with which we are not here concerned, or the Mediterranean and the Red Sea. The special features, however, of the fauna of the two last are due to the temperature of the water in their depths. The Mediterranean and the Red Sea are shut off by submarine ridges from the Atlantic and the Indian Oceans; these ridges rise to within a few hundred metres from the surface of the water, and the conditions in regard to the ocean currents do not permit any inflow from the oceans, while in any case the ridges keep out the cold deep water. As a result there are high temperatures in the water even at depths of 3000 to 4000 metres in the Mediterranean and the Red Sea; 12° to 14° C. has been registered at those depths, against some 2·5° at similar depths in the oceans. These high temperatures shut out from the Mediterranean and the Red Sea the abyssal fauna of the oceans, which is accustomed to living in the cold (stenothermal). In the place of the ocean fauna there penetrate to the abyss of the Red Sea and the Mediterranean species of animals that live elsewhere in the upper regions of the deep sea—the continental slopes and the upper bathypelagic region—being confined normally to those regions by their need for higher temperatures. Thus we find in these enclosed seas a uniform population of deep-sea creatures between about 200 and 3500 metres below the surface. This example shows the great importance which differences of temperature may have in determining the upper and lower limits of the distribution of deep-sea animals.

Differences in oxygen and carbon dioxide content matter less; these gases are present in sufficient quantity at all depths, except only, as already mentioned, in the Black Sea.

The distribution of benthal animals on the floor of the ocean is influenced not only by hydrographic factors but by the composition of the floor itself, and especially by the varying abundance of nutriment in the different sorts of deep-sea floor. These were discussed above. At 5000 metres and over, the Red Clay is the only formation observed, and its poverty in nutriment, rather than the depth itself, is the actual cause of its sparse settlement.

Then there are not so very few deep-sea animals whose distribution at higher or lower levels seems to be independent of hydrographic and other conditions. Especially among benthal animals there are invertebrates that are found almost from the region of the shore down to considerable depths. Species such as the worm *Amphicteis gunneri*, the brittle star *Ophiocten sericeum*, or *Echinocardium australe*, are distributed between the shore and 5000 metres (16,500 feet) below the surface, and much the same is known to be true of some feathered sea-nettles, Rhizopoda, snails, and mussels. Then within the actual region of the deep sea there are benthal fishes that show an extraordinarily wide vertical range of distribution: some rat tails, for instance *Macrurus sclerorhynchus*, are found between 500 and 3500 metres below the surface. On the other hand, there are deep-sea benthal animals that remain within much narrower limits in the zones distinguished above—for instance, between 400 and 600 metres on the continental slopes.

In regard to the horizontal distribution of the various species of deep-sea creatures, it used to be believed that the great uniformity and monotony of the conditions of existence in the deep sea made possible a world-wide distribution of the various species of deep-sea animals. This is largely true only of bathypelagic species; a large number and perhaps the majority of the known species of these animals are very widely distributed and are found in all the warmer oceans. Most of them, it is true, are absent from the Arctic

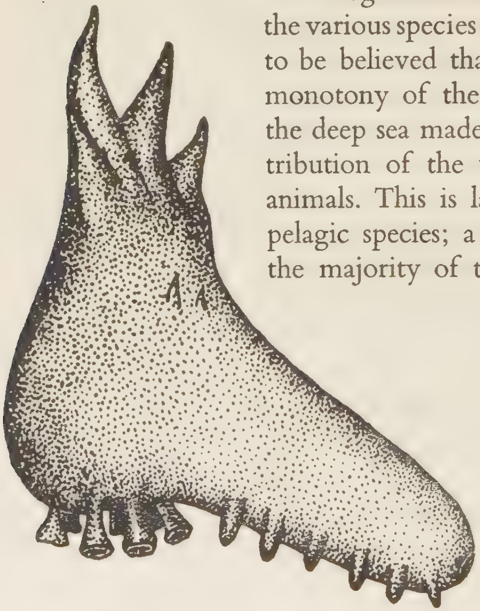


FIG. 128.—Sea cucumber (*Peniagone wyvillei*) North Atlantic, 5000 metres. Natural size.

and Antarctic, for lack of the degree of light and the temperature they need. Thus there are not a great number of deep-sea organisms of really world-wide distribution, including the Polar regions. But we have said already that deep-sea animals that prefer a low temperature are likely to be found in the upper water of the Polar seas, because they find there the temperature they need. So it may happen that one and the same species of plankton animals will be found both in Arctic and in Antarctic surface waters, but are never caught in the surface water elsewhere. This bi-polar distribution long remained a mystery, and all sorts of explanations were suggested, until the deep sea itself was recognized as the bridge between the two widely separated regions.

We mentioned above the high ridges that shut off the lower levels of the Mediterranean and the Red Sea from the outer oceans as a marked restriction on the spread of bathypelagic animals. We discussed above the effect of those ridges in producing temperature conditions in the two enclosed seas which have resulted in a special vertical distribution of deep-sea animals; but the prime cause of all this is to be sought in the restrictions placed by the ridges on the opportunities of the horizontal spread of the fauna of the deep ocean by the geographical barriers set up by the two ridges. The North Atlantic basin between the Faroes, Greenland, Iceland, and Scandinavia is also shut in by submarine ridges which cannot be crossed by the dwellers on the lowest parts of the ocean floor. As a result of this the bathypelagic and bathybenthal fauna, the world of swimming and crawling animals of the lowest depths, here shows many forms which have been found nowhere else (Figs. 100, 125, 128), while other animals found everywhere else, such as the rat tails (*Macrurus*, Figs. 38, 130), have been unable to find their way into this basin.

Other peculiarities of distribution of deep-sea animals are explained by the changes in the division between land and water in the past history of the earth's surface. Long ages ago, in the Tertiary geological epoch, an intermediate sea, the so-called Tethys, joined the western Pacific with the Atlantic through an eastward extension of the Mediterranean. To this junction the deep-sea fauna of the Atlantic and the western Pacific owes in many respects a much closer relationship than the lethal depths and the immense distances of the central Pacific have ever permitted between the animals of the eastern and western Pacific. The European and the American eel migrated through the Tethys into the Atlantic, where they are the only existing species of the genus *Anguilla.* The main region of distribution of this genus, with a considerable number of other species, is the western Pacific with the Indo-Australian seas.

Differences in the spread of benthal deep-sea animals are wider and more frequent where they inhabit the archibenthal region of the continental slopes, down to 1000 or 1200 metres below the surface. For them the environmental conditions may so vary in regard to the temperature of the water, the composition of the substratum, and currents, that archibenthal animals may have a relatively narrow field for spreading, and quite generally, it is beyond the power of the archibenthal animals to cross the abyssal depths that separate the continental slopes of the world from one another. As a consequence the deep-sea biocoenoses of the continental slopes on the opposite sides of the oceans are of very different composition, and the deep-sea populations of the continental slopes of isolated islands of early geological formation, such as the Hawaii, the Galapagos, and the Kerguelen Islands, are surprisingly rich in species not found elsewhere. The members, however, of the abyssal fauna, that is to say, the fauna of the deepest regions of the oceans, are largely distributed throughout the world, for the same reasons as those stated above in the case of the inhabitants of the bathypelagic region. For the very uniform conditions of existence in these depths make possible for many of the marine animals living there a distribution through the whole of the immense region below 3000 metres. But in the Atlantic, for instance, among the echinoderms and fishes that make up the bulk of its bathybenthal population, at most 50 per cent of the species have a world-wide distribution, and the rest are confined to the Atlantic.

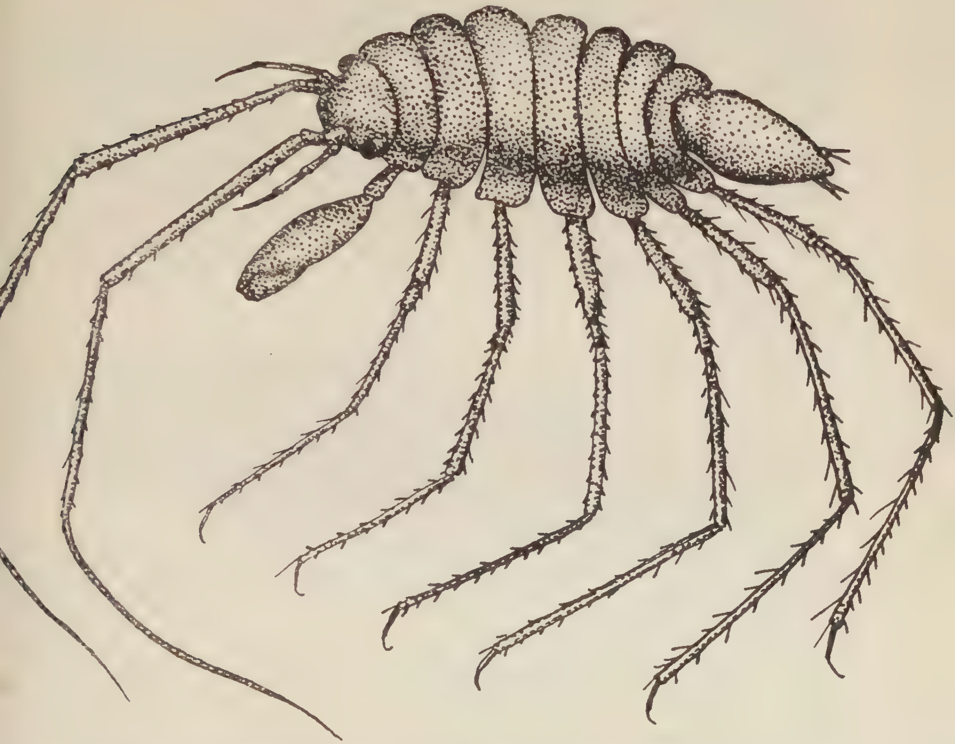


FIG. 129.—The isopod crustacean *Munna pallida*, from the mainland shelf of the Kerguelen Islands, 200 metres. Length 4 mm. (Legs shown only on the creature's left side.)

All these conditions have been closely investigated in very typical representatives of the archibenthal and abyssal benthal fishes, the rat tails (genus *Macrurus*, Figs. 38, 130). Some 130 species of *Macrurus* are known today (in the widest sense), most of them archibenthal dwellers on the continental slopes; only three of these species go below 3000 metres into the abyss. Only these and three or four other species of this genus are commonly found in other oceans. The remaining archibenthal species of the genus are not widely distributed. Thus, except in the far north none of these species of *Macrurus* are commonly found on the eastern or western continental slopes of the Atlantic, and similarly the eighteen species of *Macrurus* at present known to inhabit the continental slope of the western Pacific are not found on the west coast of America, and the rat tails of the west coast of America belong to different species from those of the east coast. Furthermore, the many deep-sea species of this genus found off the coast of the Hawaii Islands are found nowhere else.

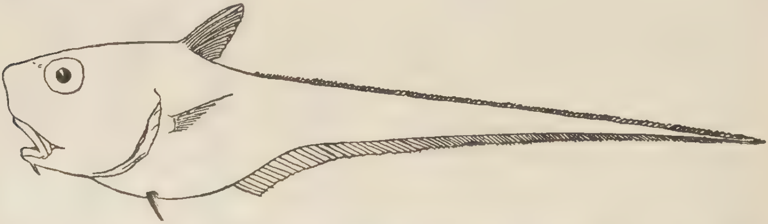


FIG. 130.—The big-headed rat-tail *Macrurus globiceps*, Atlantic, 1500 to 3000 metres. One-third natural size.

The question of the origin of the deep-sea animals, closely connected with that of their distribution, may be considered from two aspects, the ecographic or regional, and the genetic. The first has reference to the region and environment from which immigrants into the deep sea came; for although under our present-day conceptions the origin of life is only conceivable out of water, the sterile and inauspicious region of the deep sea is an unthinkable sphere of origin. The genetic aspect is concerned with the points of departure of the development up to the existing forms with all their characteristic specializations and adaptations.

The original animal world of the oceans consisted of shallow-water forms, and both the high sea and the deep sea were probably first settled from the coastal waters. It is clear from what we have learnt of the food supply of deep-sea animals that the deep sea may have first become a living-place for animals after the development of plant and animal life on the high sea. After that came the penetration of species of animals into the deep sea in two ways: the benthal animal world of the deep sea was drawn from the benthal animal forms of the coastal shallow water, as has been shown by research into the relationship between allied species of the two biocoenoses. It is not surprising, however, that many deep-sea dwellers of all oceans clearly trace their descent from forms living in the coastal and shallow waters of the Arctic and Antarctic. We have seen that a preference for a low temperature was one of the main causes of deep-sea life, and it is rather surprising to find that in spite of this the majority of deep-sea animals have their closest allies among dwellers in warm coastal and shallow waters.

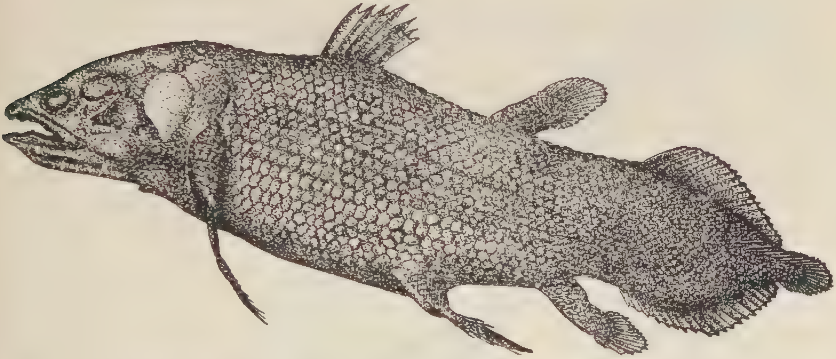
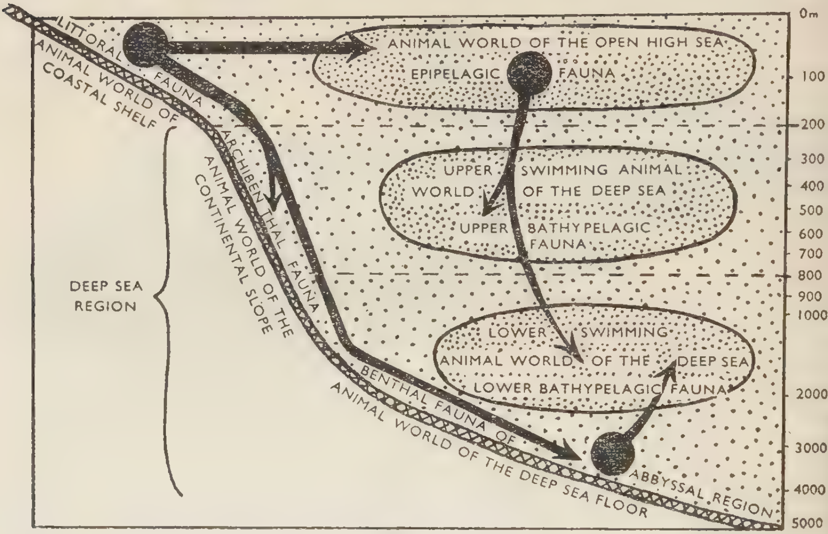


FIG. 131.—The tassel-finned *Latimeria chalumnae*. Indian Ocean, 400 metres. One-twentieth natural size.

The bathypelagic animals, those swimming in the deep sea, are descended for much the greater part from inhabitants of the high sea, the so-called epipelagic region; they have migrated into the deep sea, and spread in many cases through very considerable areas, with gradual adaptation to lower temperatures and where necessary to other ecological conditions. In the course of the change of biotope some benthal groups of deep-sea animals have quite evidently gone over to the pelagic existence, swimming in the ocean. This is certainly true, for instance, of the swimming holothurian (Fig. 5, H) and the pelagic nemertean worms of the deep sea, of the swimming octopods (Fig. 67), and of some deep-sea fishes, such as the bathypelagic Liparididae (Fig. 72), the eels (Initial letter, Chapter VIII; Fig. 82), the gulpers (Figs. 16, 80), and the angler fishes (Figs. 89-93) of the deep sea. Thus the bathypelagic deep-sea fauna has a double diocoenotic origin (Fig. 132).

Palaeontological remains from past geological epochs give, as a rule, no clue as to when the various groups of animals, the families, sub-families, and genera, found their way into the deep sea. We know that in some cases genera living in the deep sea are the most primeval of their related groups, near or distant. Since it is precisely the first actual deep-sea animals that became known to science, such as the sea lilies, corals, and Radiolaria, that included some "living fossils" whose nearest relatives belonged to long past geological ages, the Chalk, the Jurassic, or the Tertiary, the view became general long ago that the deep sea must be regarded as eminently a region into which primeval animals, no longer fitted for other habitats, withdrew, becoming extinct elsewhere. This view proved untenable in face of increasing knowledge of the animal world of


LITTORAL FAUNA
ANIMAL WORLD OF COASTAL SHELF
ANIMAL WORLD OF THE OPEN HIGH SEA
EPIPELAGIC FAUNA
UPPER SWIMMING ANIMAL WORLD OF THE DEEP SEA
UPPER BATHYPELAGIC FAUNA
ARCHIBENTHAL FAUNA
ANIMAL WORLD OF THE CONTINENTAL SLOPE
DEEP SEA REGION
LOWER SWIMMING ANIMAL WORLD OF THE DEEP SEA
LOWER BATHYPELAGIC FAUNA
BENTHAL FAUNA OF ABYSSAL REGION
ANIMAL WORLD OF THE DEEP SEA FLOOR
0m
100
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2000
3000
4000
5000

FIG. 132.—Diagram showing the great populations in the ocean and the double source of the deep-sea animal world. Colonization by the deep-sea fauna took place in the direction of the arrows.

the deep sea. For in many groups of marine animals, for example, some families of crustaceans and many of fishes, it was found that the species belonging to the deep sea were the most highly developed, and so probably the latest arrivals in their family.

On the other hand, not a few species of ancient lineage that have become known as deep-sea dwellers have aroused great interest because allied species living with them were recognized as allied to others which until then had been known only through fragmentary remains of forms long extinct. A real sensation was caused by the first capture of a living fish with tasselled fins (Fig. 131): in 1938 it was found in a net haul from a depth of some 400 metres made by innocent fishermen off the east coast of South Africa. It was of a luminous dark blue colour and about 5 feet long, and its big scales, its stalked, almost arm-like fins, and its broad and unwieldy tail made such an impression of queerness that its captors had it sent to a zoological museum. But for their care this species, of which no other specimen has been seen anywhere before, might have remained unknown to science. As it was, the fish became a world-wide sensation. It was recognized as a tassel-fin fish, a crossopterygian, and was named after Miss Latimer, the curator of a small South African museum, who had received the first official news of the capture of the fish and worked energetically for its preservation and scientific investigation. Toward the end of the earth's antiquity, some 220 million years ago, the sub-class of the tassel finned fishes (Crossopterygii) in the class of the bony fishes had formed the bulk of the ocean fishes of that epoch; after that it quickly became extinct; only one of its families, the Coelacanthidae, continued to exist throughout the earth's middle age, making in all 300 million years, from the Lower Carboniferous to the Upper Chalk. Owing to its length of existence it had been regarded as the most remarkable of all families of fish, being supposed to have become extinct in the Mesozoic; now in the *Latimeria*, regarded as belonging to it, it has continued down to our own day, another 75 million years.

The deep sea has clearly been the place of withdrawal for *Latimeria*, enabling that remarkable animal form to be preserved;

probably it does not live in the greatest depths, to judge from the depth at which it was caught and also from its bright blue colour, which is found in fishes of the upper bathypelagic region and scarcely in those of lower regions.

We owe important clues to the time and the opportunity of their immigration into the deep sea to some families of the ten-footed crabs. Here the family of the Eryonidae (Initial letter, Chapter VII) were believed to have been extinct since the formation of the Jurassic, the crab families of the Homolidae (Fig. 133) and the Dynomenidae since the Chalk, and those of the Geryonidae and Carcinoplacidae since the Old Tertiary—until recent discoveries of species living in the deep sea; they must have migrated there toward the end of the geological epochs in which they seemed to disappear. These migrations, at great intervals, of different families of crabs into the deep sea, have been attributed to great inundations of the sea, the so-called marine transgressions, which produced great

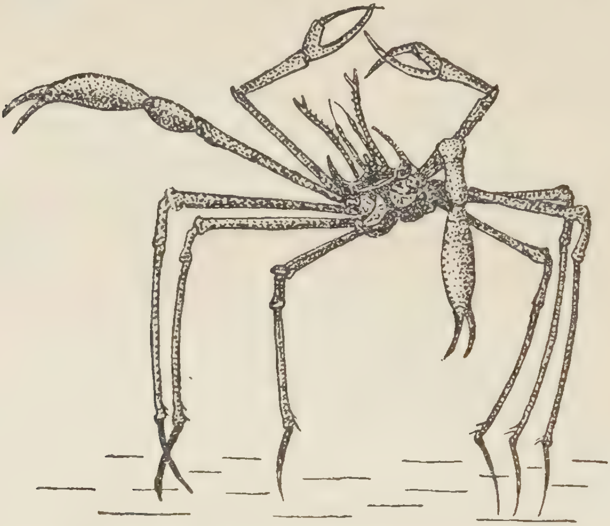

FIG. 133.—A crab of the genus *Homalochunia*, seen from in front in frog's perspective, Indian Ocean, 1000 metres. One-quarter natural size.

extensions of the shallow seas. The result was an enormous increase in the marine animal world, including the crab families mentioned. Before long the transgressions receded, and each recession meant a great reduction in the area under shallow water; the ten-footed crabs were then left with the choice between perishing in masses and finding other living-places. Many species therefore withdrew into the deep sea, where they live to this day.

Of importance, however, to the whole question of the origin and development of the deep-sea animals is the observation of the forms among the species of crab of the families mentioned, which existed in the Jurassic, Chalk, and early Tertiary epochs, and were able to exchange their shallow water biotope for the deep sea. This was possible only for those which, as dwellers in shallow water, had evolved adaptations enabling them to exist in the deep sea. For benthal forms such as these crabs, that meant primarily characteristics enabling them to move and secure food on the soft ooze at the bottom of the ocean. Among these characteristics are greatly prolonged thin spidery legs ("sea spiders") which permit movement on the yielding ooze, the atrophied eyes acquired in the life on the mud in shallow water, which remove sensitiveness to the lack of light at great depths, and an oral equipment suited to the collection of organic components of the ooze ("detritus"). Those members of the crab families mentioned which, as dwellers in the mud in shallow water, had acquired the specializations described, were able to migrate into the deep sea and to be represented there by their descendants down to the present day. Others, with short, powerful extremities, well developed eyes, and normally equipped jaws, and therefore suited to a life on firm soil in sunlit regions, and used to feeding on coarse bits of food, found no need for transfer to the deep sea, and died out.

This gives us a first glimpse of the possibilities of migration into the deep sea for dwellers in shallow water and of the acquisition of adaptations to deep-sea life. The example of the crabs mentioned shows that here, as elsewhere, animals can only settle in new and different biotopes and living spaces if they take with them certain characteristics which at least enable them to exist in the new and different conditions.

The necessary presence at least of some physical equipment and habits of life that enable an animal to maintain existence in its new biotope has been designated "preadaptation". This conception of adaptation already in existence has often been contested and rejected because, at first, there was no explanation of any possible cause of it, and research into natural phenomena is essentially research into causes. But the supposed impossibility of a causal explanation of preadaptation is only apparent, as our examples themselves show; often adaptations acquired in other contexts and kept as "neutral" adaptations, not useful but certainly not harmful in the former biotope to the animals concerned, proved their value at once in the new biotope.

On the basis of any such preadaptive characteristics that enable the animals concerned to migrate to the new biotope, further characteristics may develop which prove serviceable in the special conditions of the deep sea and so form adaptations to the new sphere of existence. Heritable adaptations, however, do not result from the direct influence of environmental conditions in face of which they would seem advantageous; no case of such inheritance of acquired characteristics has yet been proved. New and heritable characteristics come into existence again and again, though rarely and at wide intervals, in invididual representatives of species of animals, and by chance, in so far as these "mutations" are independent of the influence and the special ecological conditions of the environment. Most of the heritable changes, the mutations, prove harmful, because they make life in the given environment more difficult or impossible, and the suffering individuals come to their end instead of propagating their kind and passing on their new acquisition. But with their mutation, which proved injurious in the biotope so long inhabited, they may be able to reach a neighbouring biotope, where new characteristic proves serviceable and plays the part of a preadaptation. Or the result of the mutation may be neutral, neither helping nor harming the animals affected. Then it can be preserved. Or, finally, the new characteristic may be useful and helpful to life from the first; then, in the course of many generations, it spreads gradually, thanks to the process of heredity, which follows known laws, through the whole species.

This influence of the environment, perpetuating useful and eliminating harmful new hereditary characteristics acquired through mutations by individuals of the species living in it, is called Selection. It is also Selection that favours the more advantageously equipped species at the expense of others in the same biotope that are less well suited to the conditions of existence in the biotope.

Thus, together with Mutations, Selection is one of the most important factors controlling evolution, that is to say, the development and the change of forms in the animal world in the course of the world's history. There are five of these factors in evolution, and we have already realized the working of these two. It is clear that Selection can only favour new characteristics, or rather their possessors, if a particular characteristic is so far developed that it can be of biological advantage to its possessors. In other words, the selective factor cannot of its own accord call for new characteristics, still less useful ones, and often it has no influence on the beginnings of their development. This is well exemplified by the deep-sea angler fishes, as described above: in the males of many species of these fishes we find the first dorsal-fin ray functioning as an upper denticle bearer (Figs. 123, 134); the new characteristic is undoubtedly of biological advantage at this stage of development, because, as we saw, it facilitates attachment to the females and so the propagation of the species. Consequently the further perfection, serving this end, of this development has been favoured and fostered by Selection. But mention was also made of deep-sea anglers whose males had the first dorsal-fin ray not yet converted into an upper denticle bearer, but only, as it were, into a pointless transitional collection of small thorns above the mouth, which in these animals is of normal form (Figs. 134, 135, 136). With the development carried, however, only to that stage, the selective factor cannot possibly come into operation, since the biological advantage of the upper denticle bearer does not yet exist.

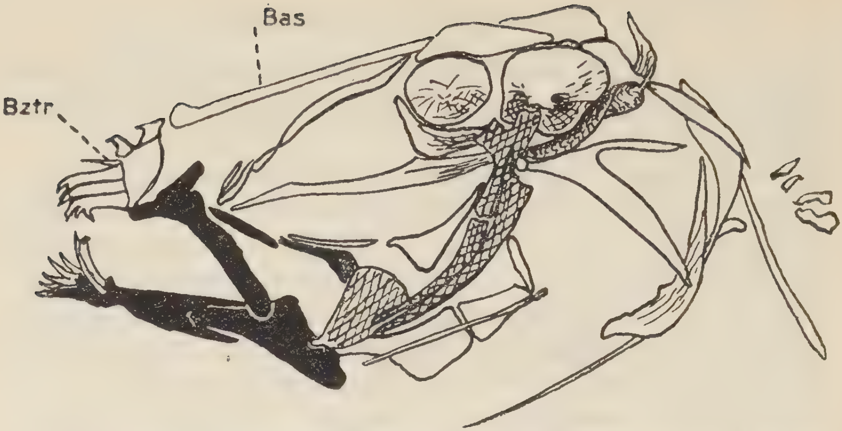

FIG. 134.—Skeleton of the head of the male (*Xenoceratias heterorrhynchus*) of a deep-sea devilfish. Bztr: the first ray of the dorsal fin converted into an "upper denticle bearer". Bas: its "fin-ray bearer". Hatched: the bones of the hyomandibular. Black: upper and lower jaws, for comparison with Figs. 108, 109, 110, and 113-117.

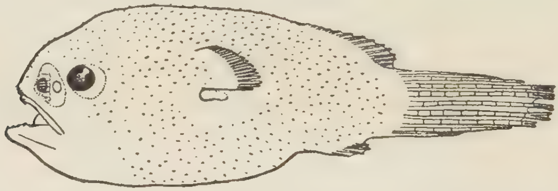

FIG. 135.—Free swimming dwarf male (*Centrocetus spinulosus*) of a deep-sea devilfish. Indian Ocean and Pacific, 2000 metres. Perhaps belongs to some such female as *Melanocetus cirrifer*, Fig. 92.

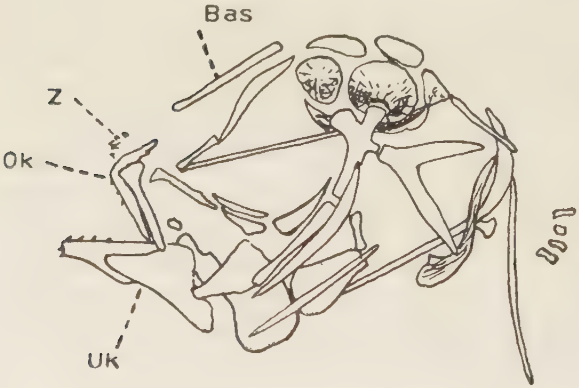

FIG. 136.—Skeleton of head of male, *Centrocetus spinulosus*, of deep-sea devilfish (Fig. 135). Ok: upper jaw. Uk: lower jaw. Z: The first ray of the dorsal fin, converted into tiny teeth above the upper lip. Bas: its "fin-ray bearer". Cf. Fig. 135.

It is another factor in evolution, the third, that may cause the spread and development of new hereditary characteristics—appearing through mutation—in the course of very long periods where the changes are not of biological advantage but just pointless, "neutral". This third factor is chance. We speak of chance where the causes of the course of events are unknown to us; but in the case of chance as a factor in evolution that does not mean that no causes exist, but only that the causes are too complicated in their working and too invisibly guided for us to be able to detect them. Thus biological chance is fundamentally different from the famous chance in microphysics, which is causeless ("acausal") by definition in the sense of the investigation of causes in natural science.

This biological chance plays a more general and a more important part than is often credited to it. It can only develop its full effectiveness, however, in conjunction with the fourth factor in evolution—isolation. To make this clear we will take a very close parallel case in human social development. Let us consider a German mountain village in about A.D. 1450, when fixed family names began to be adopted. Let us assume that the six families in the village chose the names Schulze, Vogt, Krüger, Röder, Jodelbauer, and Grunewald, and that they kept to those names from then on. The names will serve in that case as parallels to the biological incident of the appearance of new hereditary characteristics through mutation. Looking again at this village in 1850, we may find that it then had forty-eight families, of which 42 per cent were named Grunewald, 12 per cent Vogt, and 5 per cent Jodelbauer; the names Krüger and Röder have disappeared, there is only one Schulze left, and the remaining 39 per cent have names that did not exist in the village in 1450. Changes of this sort have often been found in the history of German villages. The evolutionary process here observed in the maintenance and spread of some family names adopted in 1450, and the disappearance of others, cannot have been due to the evolutionary factor of Selection, because as hereditary characteristics the names were biologically neutral; the process was due to the evolutionary factor of chance. We say it is chance that the name Grunewald has so spread in the village and the name Röder had died out, though study of the village chronicles and the church registers might reveal the causes. But chance could only produce these results because in such remote villages the people intermarry —the popular explanation and the right one; in biological terms this means that the village formed to a great extent an isolated community within the greater German community in regard to reproduction. Similarly, the members of an animal species form within the space covered by the species a number of more or less narrowly circumscribed "isolated reproductive communities". In this very fact, however, lies the working of the isolation factor, which gives the chance factor the opportunity to produce the development which we saw at work in our example in the predominance of the name Grunewald.

The four evolutionary factors which we have discussed are only able to function within the framework of the fifth and last, which is described as the factor of ecological licence, that is to say, the permission of the environment. If, that is, in the course of long processes of development, biologically pointless "neutral" hereditary characteristics are perpetuated in a species of animal simply through the working of chance and isolation, and so prevail—and without doubt this happens not infrequently—these are just characteristics which are permitted in the species in question within the framework of its ecological system of relations, characteristics which the species could therefore provide for itself, so to speak. Thus, for example, increased size beyond the normal average for the family

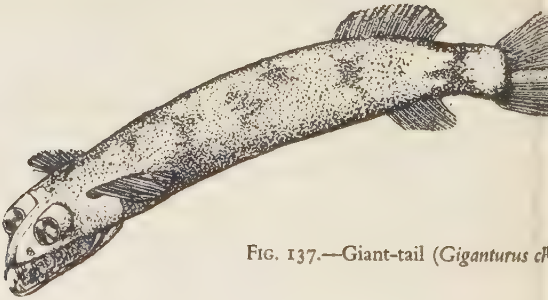

FIG. 137.—Giant-tail (*Giganturus c*

can certainly have no biological advantage for sponges or crabs; yet in the still-water regions of the deep sea members of these groups can allow themselves to grow to abnormal size, and we have seen that in fact some species of sponge (Fig. 40) and coelenterate (Fig. 41), of ostracod, isopod, and hyperiid crustaceans (Figs. 61, 97), or of other deep-sea crustaceans have grown to special size and become the giants of their whole family. Some special forms of fin formation in fishes, like the splendid crests on the head of the king of the herrings (Fig. 85) or the prolonged under-part of the tail fin of the giant-tailed fish (Figs. 12, 137), tempt one to regard them as luxury developments: these species of fish may be able to afford the luxury, but only so far as the demands of their environment, with which they are bound to comply, permit it; once more we see the factor of ecological licence at work, and we may also describe that factor as a factor of ecological or biological equilibrium. We see this factor also at work where alongside a species furnished with advantageous characteristics (which therefore are of help to it in natural selection), a closely allied species is able to maintain itself in the same biotope, without being superseded by the first species and ultimately extirpated, although it lacks the advantages in question. There live in the same regions of the deep sea two species of fish of the genus *Evermanella* (Fig. 138); the only difference between them is that one has telescopic eyes and seems in that respect better adapted to its gloomy habitat than the other, which has only normally formed eyes; yet this one seems to hold its own alongside the other. This fact (like the general fact of the living together of

ic, 1200 metres. Half natural size.

many animals, some better adapted and some less well, in the same biotope, in the deep sea for example) is made possible by the circumstance that of the countless dimensions of their ecological system of relations the whole are never entirely equivalent for any two species, so that at any time they remain at least in one respect without the competition of stronger species and are therefore able to hold their own. This situation is described by the concept of "ecological niches" of a particular character in at least one respect at any time, in which every species of animal lives and is able to maintain itself. The evolutionary factor which causes this biological equilibrium between the inhabitants of a uniform living space and so enables them to exist alongside one another, is once more that of ecological licence.

The joint operation of the various evolutionary factors in promoting the development of special deep-sea forms and of adaptations to the special conditions of deep-sea existence may be shown again in the example of telescopic eyes: the tendency to the mutative, heritable rebuilding of the eyes as enlarged and similarly pointing telescopic eyes exists in fishes, as we know; where it shows itself in species living in the light the animals affected perish, because they are less well equipped than the normal-eyed members of their group, unless they increase under artificial human protection. In this way there came into existence, like hereditary forms of the crucian carp due to breeding, the "telescopic-eye" fishes with their tubular eyes and the "sky-gazers" with their parallel upward-pointing telescopic eyes. These telescopic eyes of descendants of the crucian carps and the goldfishes are not unreservedly comparable with those of the deep-sea fishes, but they show how such hereditary formations appear from time to time in fishes and those that have them are able to survive. For fishes, however, of the regions of the last faint traces of light, telescopic eyes are biologically useful, as was shown above, and hereditary changes or mutations that produce them are favoured by Selection. But by no means all fishes living in the depths have telescopic eyes, and the very occasional and sporadic appearance of this special adaptation, which is not observed

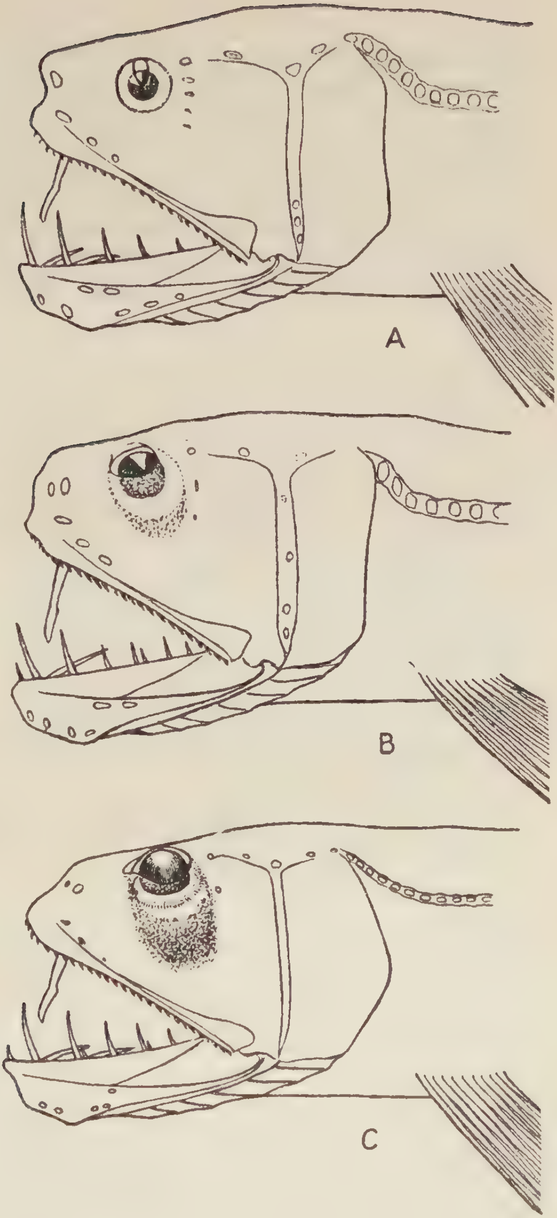

FIG. 138.—Heads of three species of fish of the deep-sea genus *Evermannella* (Atlantic and Indian Oceans, 1800 to 3000 metres): *Evermannella normalops* (A), *Ev. atrata* (B) and *Ev. indica* (C), showing the transition from normal (A) through semi-telescopic (B) to full telescopic eyes, directed perpendicularly upwards (C). 5 times natural size.

in all species of any genus, shows clearly enough how great a part is played by chance in mutative innovations and the first development of such phenomena of adaptation. We have named above (p. 156) almost all the genera of deep-sea fishes to which fishes with telescopic eyes belong, and we saw that these genera are distributed among very different orders; and mention was made of the genus *Evermannella*, whose three species show the whole process of development from normally formed eyes (*E. normalops*) to semi-telescopic eyes, not yet parallel (*E. atrata*), and on to completed telescopic eyes (*E. indica*) (Fig. 138). For the last steps in such a conversion the selective factor may be regarded as mainly responsible, while the various changes on the way to the formation of the telescopic eyes in the species possessing them proceed within the limits set by the evolutionary factor of ecological licence.

Similarly, as a result of the working of the evolutionary mechanisms indicated, we may envisage the creation of the other peculiar features which we judge to be adaptations to the special conditions of existence in the deep sea. The difficulties in the way of these conceptions presented by the development of such very unusual phenomena as the parasitism of the dwarf males on the females among the deep-sea angler fishes should not be overlooked.

CHAPTER XII

MIGRATIONS OF DEEP-SEA CREATURES

Daily and seasonal migrations – Migrations for reproduction, and migrations of the young, between the deep sea and the high sea – The "wondrous-eyed" hopping crab and the "By-the-wind-sailer" – Our eel a deep-sea fish – The strange life-history of the eel

Nothing in the life of the creatures of the deep sea is stranger than their migrations. We will confine ourselves here to those with a regular, habitual course.

We may distinguish horizontal and vertical migrations, those into distant regions, and those into the upper water. We may also distinguish, in accordance with their ecological context, between migrations for subsistence and migrations connected with the reproduction of the species. Finally, in respect to the rhythm of repetition of these wanderings we have to do with daily migrations, seasonal ones, and those connected with the growth and development of deep-sea animals. All these categories run into one another and overlap in all sorts of ways.

Hunger and the reproductive instinct, the two most powerful driving forces in animal life, supply strong motives for these migrations. Other occasions for them exist in global changes, especially variations in hydrographic features such as temperature, currents, salinity, and oxygen and carbon dioxide content of the sea water; these especially determine the rhythm of seasonal and daily migrations. Changes in the environment also occasion migrations of many predatory animals, as they produce migrations of the small animals on which the predators feed; and it is probably the combined operation of external and internal, presumably hormonal, influences that determines the migrations connected with the reproduction and the development of deep-sea animals. At present there is very scanty knowledge of many of the details of this complicated play of diverse causes which must necessarily act together.

To begin with vertical migration, the passive ones are usually of little importance to the life of the species concerned. This is true of involuntary sinking due to injuries or to sudden changes for the worse in the environment, both usually fatal, and of upward movement due to irresistible upward currents. Passive sinking to destruction is, of course, of biological importance to the food supply of the deep sea, while sudden upward currents have often brought to the knowledge of scientists animals which could in no other way have been wrested from their gloomy habitat.

More important are the active upward migrations, or at least those which play a significant part in the life of the animals concerned. We have mentioned the two ways of bringing them about, active propulsion by means of fins or other propelling organs, for instance the regular beats of countless little lashes of the sea gooseberries, or the contraction and expansion of the edges of the umbrella of other jellyfishes; and secondly the alteration of specific gravity to the same end by means of hydrostatic mechanism, as in the gas bladders of the Portuguese man-o'-war, or the swim-bladders of fishes, or, lastly, the storing of oil in their body for the purpose of altering specific gravity.

Many deep-sea creatures rise regularly at night to higher levels of the water, even to the surface. This is done among the fishes by a great number of lantern fishes, and by some stomiatoids such as the *Astronesthes* and *Idiacanthus* species. They are able to make the journey of hundreds of metres for the very reason that they have no swim-bladder. We have said already that the dwelling of many animals in the depths is clearly due to their dependence on darkness, especially as the distribution of many of them is closely connected with the depth to which the daylight penetrates into the water in different latitudes. Dislike of light may also be the reason for the habitual stay of the fishes mentioned at a depth of 500 metres below the surface through the day and their quite regular ascent to the surface at the approach of darkness; not the least of the reasons for this is the better supply of food at the higher level. In this circumstance lies the biological advantage of the nightly change of level.

The plankton, too, migrates vertically every twenty-four hours; this migration has been closely investigated in the case of *Calanus finmarchicus*, the most prolific species among the planktonic crustaceans in the North Atlantic. Its immense shoals keep to about 100 metres below the surface during the day, and at night keep near the surface. These vertical migrations of the plankton do not extend to the deep sea, but they show that the plankton organisms, in spite of their dependence on currents and incapacity to make distant migrations at will, are capable of regular movements up and down and vertical changes of level. Many other plankton animals, including jellyfishes and also the minute unicellular Radiolaria, go deeper in stormy weather; they evade the dangers to their delicate structure of rough treatment by the disturbed water.

Vertical migrations in connexion with the seasons are also characteristic of many deep-sea fishes; they seem to depend mainly on temperature requirements, the temperature of the water at particular depths varying with the season. The *Valdivia* Expedition found a seasonal change of depth in the *Salpa fusiformis*, a tunicate. Like some others of the larger plankton animals, these salps are often to be found in extraordinary numbers on the surface of the sea in cold weather, but when the water gets warmer they go down to 1000 metres or more below the surface, to be able to remain in the temperature they need.

The most varied and complicated phenomena of vertical migration between the deep sea and the upper water are connected, however, with the reproductive habits of many marine animals. In most cases these migrations take this course: the young forms, almost always differing greatly from the adult stage, the larvae, or less frequently the eggs, rise independently or by means of hydrostatic equipment at least up to the limit of the penetration of day-light, benefiting there until they reach maturity from the better subsistence. We have seen some of their changes of form in the course of their growth, and they are particularly comprehensive when the adult is a sessile animal and the larva, as almost always, freely swimming.

The reverse sometimes happens, though much less often: the adults live on the floor of the ocean or in shallow water or in the high sea, and the young live in the deep sea during the period of growth. And finally we know of a few deep-sea dwellers with the remarkable characteristic of leaving their habitat in the depths only for the union of the sexes in the sunlit upper water, while the eggs then laid or the quickly moving young sink back into the deep sea. Examples of this peculiarity are the behaviour of the hyperiid crustaceans *Phronima* and *Thaumatops* (Fig. 97), of the order of Amphipoda, which latter genus was mentioned above as the giant of its order. The males of *Phronima* live freely at considerable depths in the ocean, the females at rather less depth in the tests of tunicates of the genera *Doliolum* and *Pyrosoma* which they have cleared. The two sexes rise to higher levels of the water for their union, and there the females lay eggs in the tests in which they have been living. The young seek the depths at once. The two sexes of *Thaumatops* go up from the depths to the limit of the penetration of light; the eggs laid there sink at once into the deep sea.

The comparatively rare case of the rising of eggs laid in the deep sea is known especially among jellyfishes inhabiting the depths, but also among some fishes, including the benthal rat-tails (*Macrurus*). Almost always among echinoderms, crustacea, and countless species of deep-sea fish the young larvae rise into the upper water; the plankton is largely made up of such deep-sea animals.

A very remarkable example of reproduction migration from the high sea into the deep sea is offered by the "Before-the-wind-sailer", as seamen call it—the jellyfish otherwise known as a siphonophore (it is a colony of individuals on a stem), genus *Velella*. This animal belongs to the high sea, and is often to be seen drifting on the surface in great shoals, with its air-filled gasbag, provided with a sail, floating high above it (Fig. 7). The sexual polyps on which the reproduction of the whole colony depends detach themselves from the stem before they are mature, and push their way, in the form of small jellyfishes, down to depths of over 1000 metres; only then do they mature and reproduce their species. The larvae of *Velella*, which are very unlike the adult animal stem, then return to the surface, where they fill their gasbag, which has developed by then, with air and grow into the complete animal stem.

The biological importance of the rise of eggs or larvae of deep-sea animals to the upper water, and their development there, lies once more mainly in the opportunity of benefiting from the better subsistence there. At the same time this form, the most frequently observed, of vertical reproduction migration of deep-sea animals has the genealogical significance of an indication of the origin of these deep-sea species in the surface fauna of the high sea (the epipelagic region) or the benthal fauna of the shallow water (the littoral). The migration of the adults into the sunlit regions for reproduction, as with *Phronima* and *Thaumatops*, may find its biological advantage in the help given by the light toward the meeting of the sexes: they can find one another more easily.

Nothing is known about the horizontal migration of deep-sea animals except in cases in which they rise from the depths for that purpose. It is not even known whether such migrations are made, or by which species. There is precise information, however, though dating only from recent decades, of the migration through immense distances of the European and the American fresh-water eel. The eel divides its life between the deep sea and the rivers of the continents. For the eel, that familiar delicacy found in the ditches far inland, is a true deep-sea fish; every eel is born in the deep sea and returns to it, unless it reaches our table or suffers some other mischance. Only by means of modern oceanographic methods did it become possible to throw light on the strange and mysterious life-history of the eel, though it had puzzled men's minds for ages to answer the question how and where the eel reproduced its kind.

It was known in ancient times that the eel comes into rivers and inland waters from the sea. Little eels, bright as glass, only 2 to 3 inches long and as thin as a match, come in spring in enormous numbers to the estuaries of the European rivers, a little earlier along the Atlantic coasts than on the shores of the North Sea and the Mediterranean. They go up the rivers, against every current, and distribute themselves among the smallest rivulets and ditches, reaching the remotest waters. They climb over rocks, wriggle past rapids, negotiate damp moss and any other difficulty in their way. Meanwhile they begin to colour, and soon they begin their life on the bottom of our inland waters, lying all day buried in the mud, going after their prey at night, and getting bigger.

It has been found that this inland voyage is made almost solely by the females, the males remaining in the estuaries in brackish water.

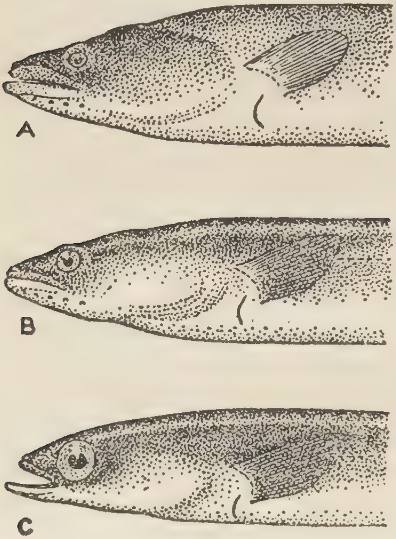

Fig. 139.—Stages of development of the head of the adult fresh-water eel. A: Yellow eel; B: Silver eel; (C) deep-sea eel.

Five years later, when the males are 18 inches long and the females 4 feet (and weighing up to 12 pounds), the eel changes from the "yellow eel" that it was into the "silver eel": its back becomes darker and its belly white with a metallic sheen; its eyes grow bigger, the sexual glands swell, and the digestive organs atrophy (Fig. 139). The silver eels now leave their haunt, sometimes even when they have been placed in ditches with no outflow; for at night they are able to cross meadows damp with dew. Now they go downstream to the sea, and there disappear. What then happens to them, where they establish themselves, and what happens after that, until the young glass eels show themselves in the estuaries, remained until quite recently a mystery.

The mystery was finally cleared up by the tireless work of the Danish scientist Johannes Schmidt, who devoted decades to its unravelling. After their descent to the sea the adult silver eels migrate rapidly through the Atlantic, probably at a great depth from the first, to a fairly closely delimited area in the Sargasso Sea, lying about midway between Puerto Rico and the Bermuda Islands and stretching eastward for some distance. There they spawn, though probably not on the bottom of the ocean, which in that region is 6000 metres or 20,000 feet deep, but in the sea at depths between 1000 and 5000 metres. It is supposed that the old eels then die; in any case, they never return and are no longer found in the ocean.

From the eggs come young that have little resemblance to their parents. They are entirely transparent, narrow, ribbon-shaped, and long (Figs. 83, 84); they were given the name *Leptocephalus*, and were regarded as a separate genus until the Italian scientists Grassi and Calandruccio identified these strange little fishes as larvae and young of the eel. The larval life of the European eel lasts three years, and during that time the *Leptocephalus* larvae, which come up near the surface of the water at an early age, make the whole journey across the Atlantic; meanwhile they gradually grow into the shape familiar to us, until as glass eels they enter the European rivers.

These are the simple facts of the mysterious and very unusual life-history of the eel. But the causes of this remarkable and complicated behaviour, the factors that account for the journeys of the silver eels to their spawning place and the *Leptocephalus* larvae and glass eels to the European coasts and inland waters, are still almost unknown and only a matter for conjecture, which, it is true, may prove correct.

No doubt the change of the yellow eels into silver eels and the succeeding migratory instinct with its "negative rheotaxis", that is to say the effort to move always with the current and so ultimately into the sea, are the result of the working of hormones formed in the growing sexual glands. The conversion of the eel's little eyes into the big ones so often found in deep-sea fishes proceeds simultaneously with the other changes. The marked aversion to light, the "negative phototaxis", of the eels explains their penetration into the depths and their remaining there as soon as they reach the ocean. But neither in this nor in any sort of relation to currents can we find a clue to the mystery of their ability to find their way to their fairly narrowly circumscribed spawning-place in the western Atlantic. Nor can chemical influences, such as changes in the concentration or composition of the salt content of the sea water, yield the guiding mechanism for the migration to the breeding area, as thorough consideration and investigation have shown, and it is quite inconceivable that the eels should have remembered it from birth. Birds of passage may pass features that serve later as reminders of their course, but there are no such features in the deep sea.

A possible explanation of the eels' guidance to their breeding area has been found, however, in the temperature conditions in the Atlantic, in association with the temperature needs of the eels, and it is claimed that it throws light both on the problem of the migration and on the origin of the migratory habit of the Atlantic species of eel. During their migration the eels' stenothermy, their need for a particular narrow range of temperature, grows, and they show the condition of "positive thermotaxis", an instinctive pursuit of a particular region of temperature, their "optimum" range. Water of a temperature of 17° or 16° C. is essential to the eels' reproduction; the eggs and the minutest larvae are found exclusively in deep waters of the Atlantic with that temperature, and that temperature is found only in the narrow region of the Atlantic between 55° and 68° west longitude, in which for that reason the spawning area of the eel is situated. And it is quite obviously the eel's growing stenothermy, together with positive thermotaxis and negative phototaxis, that leads the eel to its spawning-place.

The migration of the eel larvae back to the European coasts is more variously guided. To begin with, they are of positive phototaxis, that is to say, they make for the light and so rise to the surface layers; they may also be driven by currents toward the west European and north-west African coasts and into the Mediterranean, the North Sea, and the Baltic; they may also be influenced by salinity and other hydrographic factors. Since as quite young larvae they live in the plankton, it takes them three years to drift to the coasts of Europe, and their larval life lasts during that time (Fig. 140).

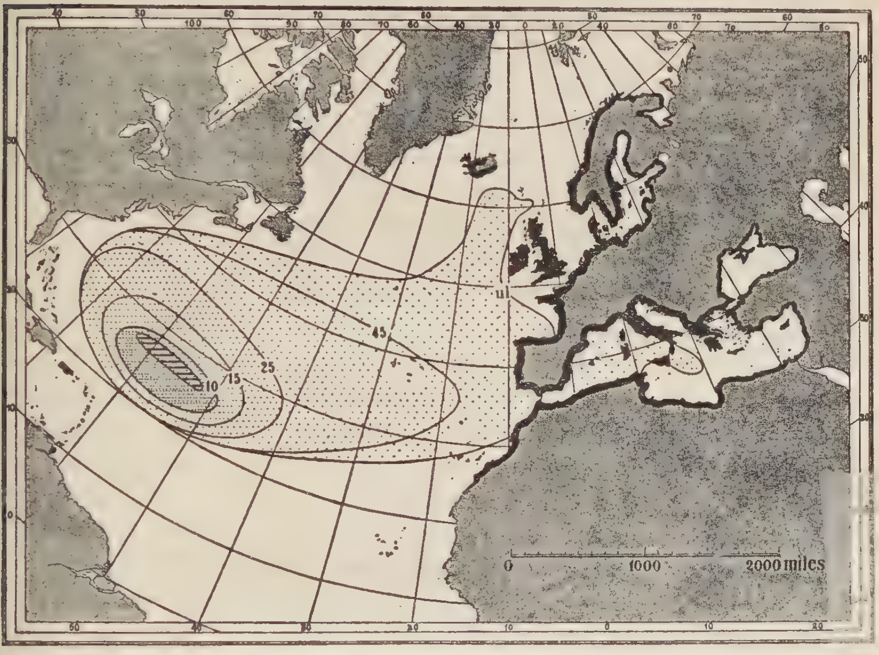

Fig. 140.—The distribution of the European fresh-water eel in its different stages of development. Black: the coasts visited by the "glass eels" for their change of habitat to fresh water. The figures give the length of the different stages of development of the "Leptocephalus" larvae and through the lines associated with them the further spread of each; *ul* shows the extreme limit of appearance of Leptocephalus larvae not yet transformed into "glass eels". The hatching within the 10 millimetre length limit shows the spawning place of the European fresh-water eel in the depths of the Atlantic.

The European eel spawns near the American coast. Why did it decide for the much longer migration to Europe and back again, and for the long larval period, unusual in eels, of three years? The question is not put rightly in that form, as will soon be clear, but it is the more natural to put it so since the European and North African eel, *Anguilla vulgaris*, shares the spawning-ground with another eel, the American *Anguilla rostrata*, whose young has a larval period of only one year, during which it covers the shorter distance to the American rivers. It must be assumed that the deep sea is the original home of these two species of the genus *Anguilla*, as to this day it cradles every individual eel; and we can scarcely even guess how through immense periods long ages ago the eel came to make anew in each generation the enormous journey from its living-place, and indeed from the sea, to the remotest inland waters of the continents and then back again to the place of its origin. When, however, the two Atlantic species of *Anguilla* have for their home the same limited deep-sea spawning-place, why does one of them migrate to the distant European coasts and not the other?

The answer lies very probably in the changes, over a long period, in the conditions of existence in the eels' deep-sea home. As we have said, their need for a water temperature of about 17° C. at a depth of about 500 metres confines them to their present spawning-place in the West Atlantic—both the European and the American species. In the past, however, in the Ice Age, the region of the uniform temperature of 17° C. at 500 metres must have included the whole of the central Atlantic from 20° to 80° W. It must be supposed that during the period of this wide extension of the 17° region in the Ice Age the American *Anguilla rostrata* spawned in the West Atlantic and the European *Anguilla vulgaris* in the East Atlantic. Both species then had about the same distance to cover to the coast they preferred, and both about the same time to cover it. When, however, in the succeeding geological period down to the present age, the 17° region grew steadily less and shrank westwards, the European and North-west African eel found its spawning-place farther and farther from its continental home. The species was then in danger of extinction owing to the increased duration of the larval period and the increased ocean journey imposed on the larva. It would have died out if its range of variation and mutation had not included the possibility of increasing the length of its larval period and so the time it could take for the longer journey to the European and African coasts. So it was that in the end the two Atlantic species of *Anguilla* sought the same spawning-place in the West Atlantic. And the very different hereditary reactions of the larvae of the two species to the particular combinations of light, salinity, currents, and temperature conditions in the ocean produce inevitably the result that the larvae of one species are guided to the American and those of the other to the European and north-west African coasts.

The other species of eel live in the eastern Indian Ocean and the western and southern Pacific; they too migrate from the ocean into fresh water and return to the ocean to breed. From those regions, the main regions of distribution of the genus, come without doubt the two western species of eel. They found their way through the former Tethys into the Atlantic Sea, that great middle sea which from the epoch of the Cambrian, the early global antiquity, to the middle Tertiary existed between the northern and southern continents of the earth.

We have to understand all the strange phenomena of animal life in the deep sea as a balance between the developmental, functional, and instinctive-physiological means of behaviour of its settlers and their one-sided environmental conditions. Here again, therefore, it is essentially an ecological problem, one concerning the relations between animal and environment, which the phenomena of existence in the abysses of the oceans set before us. From the answers so far discoverable we have sought to comprehend the strange world of the deep sea. And in this same direction a rewarding field still awaits research, which as it proceeds steadily adds to our knowledge of the various deep-sea animals. A sensation such as the discovery of the deep-sea tassel-finned fish *Latimeria* in 1938 was worthily followed, though to the uninitiated less amazingly, by another when, quite recently, a supposed tube-worm, brought up from 3500 metres in the Sea of Okhotsk, was shown to be a representative of a hitherto unknown class of the same rank as the echinoderms, the arrow worms and the allies of the cephalopods or the vertebrates—the Pogonophora. But let us give an instance of the painstaking detail-work that is the foundation of deep-sea research: for the quantitative research that is of infinite importance to our knowledge of the maintenance and the distribution of living beings in the ocean, a plankton expedition devoted 3½ months to the collection of plankton organisms; their segregation and counting took 3½ years.

SOURCES OF THE ILLUSTRATIONS

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Sources of drawings and adaptations

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